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ABSTRACT

This document is the second of three volumes of the proceedings an international seminar which focused on student misconceptions in science and mathematics as well as teaching strategies intended to deal with those misconceptions. An introduction to the volume explains the format of the conference and the organization of the sessions. It stresses the attention given to constructivism by the participants, as well as some of the problems associated with defining misconceptions and alternative frameworks. The remainder of the document contains 51 of the papers presented at the seminar, arranged in alphabetical order by senior author. These papers covered such topics as teacher education, teaching strategies, biology, and elementary science. Also included is a list of the conference participants. (TW)

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Proceedings of The

Second International Seminar

MISCONCEPTIONS AND EDUCATIONAL STRATEGIES IN SCIENCE AND MATHEMATICS

July 26 - 29, 1987

CORNELL UNIVERSITY, ITHACA, NY, USA

Volume II

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PROCEEDINGS CONTENT BY VOLUME

VOLUME I: Overview of the Seminar; Epistemology; Research Methodologies; Metacognitive Strategies; Use of Computers; Roster of Participants

VOLUME II: Overview of the Seminar; Teacher Education; Teaching Strategies; Biology; Elementary Science; Roster of Participants

VOLUME III: Overview of the Seminar; Physics; Mathematics; Chemistry; Roster of Participants

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Second International Seminar
Misconceptions and Educational Strategies in Science and Mathematics
July 26-29, 1987

Introduction

Our first seminar, held in 1983, showed that there was strong international interest in the general topic of student misconceptions in science and mathematics (see Helm and Novak, 1983). Advance announcements for our second seminar were more widely circulated, but the fact that over three times as many papers (177) were presented and more than three times as many participants (367) enrolled from 26 countries was clear indication of the great interest currently evidenced in the field. The proceedings are being printed in three volumes to accommodate all papers submitted. A roster of participants is included in each volume.

The format for the seminar followed the pattern of our first seminar: a wine and cheese informal reception on Sunday evening; morning and afternoon sessions for paper presentations and discussions; late afternoon plenary sessions to discuss "Issues of the Day"; and unscheduled evenings. There was the frustration for most participants of choosing between seven or eight simultaneous sessions, but papers were grouped by topics in an attempt to preserve some homogeneity of interests in each group. Papers are presented in the Proceedings in broad general categories similar to the groupings used in the seminar program, and in alphabetical order by senior author.

Meetings of the Psychology and Mathematics Education group were scheduled in Montreal, Canada just preceding our seminar and this facilitated participation by a number of math educators who might otherwise not have attended. In both our first seminar and again in 1987, there was a strong feeling that researchers in science education and in math education can benefit by greater interaction. Although parallel sessions devoted to science or math education research limited some of this interaction, plenary sessions and informal meetings offered some opportunities for much needed cross-disciplinary dialogue. There was a general consensus that many of the issues and problems were common to both science and math education. In some areas of research, math education appears to more advanced than science education (e.g., concern for epistemology as it relates to instruction) and in other areas the reverse is true (e.g., the use of metacognitive tools to facilitate understanding). In the plenary session on physics and chemistry, similar concerns were evidenced in communication between sciences.

There remains the problem of definition of misconceptions, alternative frameworks, or whatever we choose to call these commonly observed patterns in faculty understanding evidenced in students, teachers and textbooks. There were more papers presented in this second seminar on how to deal with misconceptions than in the first; however, there was still heavy representation of papers dealing with the kind, number and tenacity of misconceptions and probably too few dealing with educational strategies to mollify or remove the deleterious effects of misconceptions or to limit teacher or text initiation of misconceptions.

More emphasis was evidenced on the importance of epistemology to improvement of science and math education. In general, there was strong endorsement of "constructivist" epistemology both for clarifying the nature of knowledge and knowledge production and as an underpinning for lesson planning and pedagogical practices. Of course, there was debate on the value of constructivist ideas and even some questioning of constructivist epistemology in contrast to empirical/positivist views on the nature of knowledge and knowing. A number of participants observed that we promulgate constructivist thinking for students, but too often we conduct teacher education programs that seek to give teachers fixed truths and methodologies, rather than recognize their need to reconceptualize subject matter and pedagogical strategies as they engage in the slow process of conceptual change.

Although concern for teacher education was better represented by papers in this seminar than in our first, there remained a common perception that new ideas and methodologies to improve teacher education, and much more field-based research in teacher education, are badly needed. As we launch this year at Cornell University a new science and mathematics teacher education program, with new faculty, we were especially sensitive to the concerns expressed. They represent an important challenge to us as we move ahead in the design, evaluation and analysis of our new teacher education initiatives.

In our closing plenary session, Ron Hoz expressed concern for the limited representation of papers dealing with the psychology of learning as it relates to science and mathematics education. This concern appears to be warranted in view of the fact that most psychologists interested in human learning have abandoned bankrupt ideas and methodologies of behavioral psychologists (e.g., B.F. Skinner), and are now developing and refining strategies for study of cognitive learning (e.g., James Greeno). The early work of Jean Piaget, George Kelly, David Ausubel and other cognitive psychologists is now entering the mainstream of the psychology of learning. These works have important relevance to the study of teaching and learning as related to misconceptions. A note of caution, however. Most of the behaviorist psychologists turned cognitive psychologists still operate methodologically as positivists. They hold constructivists views of learning (i.e., that learner's must construct their own new meanings based on their prior knowledge), but they adhere to rigidly positivist research strategies and often recommend teaching practices that ignore the teacher as a key player in constructivist-oriented teaching/learning. The "constructivist convert" psychologists were conspicuously absent from our participant roster. What is the message here?

There were more papers dealing with metacognitive tools. This may reflect in part the rising national concern with helping students "learn how to learn." Almost every issue of the journal of the Association for Supervision and Curriculum Development (Educational Leadership) has articles on this topic extolling the merits of efforts to help students acquire "thinking skills." Another word of caution: a backlash is already developing in the American public that schools are so busy with numerous activities to teach "thinking skills" that too little subject matter is being taught! My own view is that most of the "thinking skill" programs lack solid underpinning in both the psychology of cognitive learning and in constructivist epistemology. They are too often an end in themselves, rather than a means to facilitate learning and thinking that places responsibility on the learner for constructing their meanings about subject matter. Concept mapping and Vee diagramming are two metacognitive tools that have had demonstrated success in this respect, as reported by a number of papers in Volume I of these Proceedings. From our perspective, we should like to see much more research done on the use of metacognitive tools to help teachers help students modify their misconceptions and form more valid and powerful conceptual frameworks.

In the mathematics groups in particular, but also in some of the science sessions, there was concern expressed regarding the importance of "procedural knowledge" as contrasted with "conceptual knowledge." Students often learn an algorithm or procedure for solving "textbook" problems but cannot transfer this skill to novel problem settings or across disciplines. They fail to understand the concepts that apply to the problems. The contrast between "procedural" and "conceptual" knowledge is, in my view, an artificial distinction. In our work with sports education, dance, physics, math and many other fields, we have never observed a procedure that could not be well represented with a concept/propositional hierarchy in a concept map. The limitation we see is that both strategies for problem solving and understanding basic disciplinary ideas derive from the conceptual opaqueness of most school instruction. Mathematics, voice and dance instruction are particularly bad cases of conceptually opaque teaching. Metacognitive tools such as concept mapping can reduce some of the dilemma evidenced in concern for procedural versus conceptual learning to the need for more research and practice to help teachers help students see more clearly the conceptual/propositional frameworks that underlie meaningful learning and transferability of knowledge.

The role of the computer in science and mathematics education is emerging more prominently. Several sessions dealt with papers/discussion on the use of the computer as an educative tool, and numerous other sessions had one or more papers that reported on studies that involve computers in some way. The rapidly increasing power and stable cost of microcomputers, together with better and easier authoring systems, are changing significantly the application of computers in science and mathematics education. In many cases, the computer is not a substitute for class instruction but rather a tool for extending learning in class to novel problem solving or simulation constructions. The use of the computer to provide directly large amounts of raw data, or to permit access to large data banks, makes possible problem solving activities that border on original research, thus providing opportunities for creative problem generation and problem solving by students in ways that offer an experience paralleling creative work of scientists or mathematicians. The emerging use of video disc with computers and the emerging technologies for monitoring laboratory experiments should provide exciting new opportunities for science and mathematics instruction and also for the use of metacognitive tools. We expect to see much more activity reported in this area of future seminars of our group.

It is interesting to note in passing that while video tape was often recognized as a powerful tool in research on teaching/learning and for teacher education, not one paper reported on the use of TV as a primarily teaching vehicle.

The much heralded power of television as an instructional vehicle in the 1950's has not materialized. What will be the fate of computer aided instruction or interactive video instruction in 20-30 years?

On occasion, especially in sessions dealing with teaching and teacher education, it was observed that the school and classroom are complex social settings. We know much too little about how social factors facilitate or inhibit acquiring or modifying and correcting misconceptions, or indeed any other learning. There is a need for an enormous increase in studies dealing with the school/teacher/learner sociology as it relates to misconceptions research. We need to learn more about what sociologists, anthropologists and linguists are learning about how people communicate or fail to communicate positive ideas and feelings. It is my hope that our next international seminar on misconceptions will reflect more knowledge and awareness of these fields.

There remains much work to be done. And yet there are reasons for optimism. We are learning more about why students fail to learn and how to help teachers help students learn better. I believe the science of education is building a solid theory/research base, and positive results in improvement of educational practices are already emerging. The next decade should bear fruit in tangible improvement of science and mathematics teaching.

Reference

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Strategies for developing affective outcomes of talented children in school mathematics.

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A vast majority of schools in India gear their mathematics curriculum and instructional strategies to serve the needs of the average and below average children in schools. The mathematically talented children in schools are either totally ignored or given some kind of extra coaching which will usually be inadequate to exploit their full mathematical potential. A small number of voluntary agencies like the Association of Mathematics Teachers of India (AMTI), or official agencies like the National Council for Educational Research and Training (NCERT) organize a limited number of programs for the benifit of the mathematically talented students in schools and colleges in India. Their work however is limited to the identification of the mathematically talented students using a complex series of mathematical problems (the Mathematical Olympiad, or the National Talent Search). While some of the identified students are considered for scholarships or advanced educational placements there is no systematic attempt to train the talented in the advanced areas of mathematics. The few programs available are mostly confined to cognitive outcomes in select areas of mathematics. There is little or no attempt to develop affective outcomes with respect to mathematics and allied areas. We know from

research that developing affective outcomes like favorable attitude towards the subject or better interest in the subject is a more fool-proof method of retaining the talented persons in the field.

The problem and its rationale

This paper is based on a project conducted for talented students in secondary school mathematics attending Standard X (the tenth grade) in the schools of the state of Kerala, India. (The author who is a senior officer in the State Institute of Education (SIE), Kerala, (the academic wing of the State Directorate of Education) was in charge of different programs for the mathematically talented students in the schools of Kerala since 1983.) Since there was a dearth of adequate teaching strategies for developing affective outcomes in highly talented mathematics students of Standard X, it was decided to test a series of specially designed strategies for this project.

Based on the author's experience the following six strategies were selected for the study (the author had in the course of her carrer as a mathematics educator and resource person, given in-service education to senior mathematics teachers and tried out many strategies which she considered useful in making affective changes in the learner):

1) Seminars on cricial conceptual areas in mathematics,
2) Directed library reading sessions,
3) Popular lectures and demonstrations by reputed mathematicians,
4) Conduct and reporting of mathematical projects

by students with the assistance of specialists,

5) Organization of mathematical exhibitions by students, and

6) Creative mathematical teaching sessions.

Methodology

The six strategies were tested during the academic year 1984-85 on a group of 60 mathematically talented subjects, in two districts of the state of Kerala, Trivandum and Quilon.

a) Identification of the talented: This was done using the results of the State Talent Search examination in mathematics conducted by the SIE. This examination is conducted annually in all the schools of the state to cover all students scoring 60% or above in the class examinations of Standard X. These students take the Talent Search examination which consists of 30 multiple choice items based on the mathematics syllabus of Standard X of the state. The items are selected from a question bank in which the difficulty level of the items are reported. Only items of difficulty level 25% and less (items which only 25% of the general population of students of Standard X complete successfully) are included in the test. The top 30 students from each district are selected based on the scores for this test. Normally about 1000 students take the examination from each district. The top 30 students in two districts, Trivandrum and Quilon, were used for testing the effectiveness of the select six strategies.

b) Assessing the effectiveness of the strategies: Each of the six strategies were applied one after the other by a team of expert teachers on the selected sixty students using the procedure detailed later. The experimental group was tested before the operation of the strategies for the following affective variables.

i) Attitude towards mathematics
ii) Interest in mathematics
iii) Value for the power of mathematics

The experimental group was given a second test using the test material at the end of the instructional sessions (using the strategies). The scores in each of the above three variables were collected for the sixty subjects before and after the instructional sessions. The mean scores before and after the sessions were compared using the conventional t-test for large dependent groups. All the t-values derived were significant well beyond the 0.01 level, showing that the six instructional strategies in combination have produced significant changes in each of the three affective variables among the students.

c) Instruments used for comparing the affective outcomes: Three standardized tests were used for measuring the affective outcomes. "Attitude towards mathematics" was measured using a 20 item attitude scale of the Likert type, with three point scoring system for each (agree, neutral, and disagree). "Interest for mathematics" was measured using a 20 item scale in which the subjects were required to select one activity from three alternatives given in each item. The test for measuring the "value for the power of mathematics" consisted of twenty items, for each of which the student was required to respond by putting a '✓' mark against one of the three response categories - agree, undecided, or disagree. The scales are given in Appendices I, II, III.

d) Instructional Strategies: The six strategies used are the following.

(i) Seminars on crucial conceptual areas in mathematics: The students were made to participate in seminars on three conceptual areas viz. (a) mathematical system without numbers, (b) a finite geometry based on a defined set of postulates in six-point space and (c) an unusual algebra developed from switching circuits involving series and parallel connections.

(ii) Directed library reading sessions: Fifty selected books were displayed in the library with short notes about the contents of each book on the cover page and the students were encouraged to read selected areas of at least four books under the supervision of the instructors.

(iii) Popular lectures and demonstrations by reputed mathematicians and mathematics educators: Lectures were arranged by five eminent professors on the following topics:

(a) Kerala's heritage in mathematics,
(b) Recreational aspects in the study of mathematics,
(c) Application of mathematics in social sciences,
(d) Non-Euclidean geometry, and
(e) Computers in the modern world.

(iv) Conduct and reporting of mathematicsl projects by students: Each student was helped to complete a project either on his own or in a team of three students under the guidance of senior teachers.

(v) Organization of mathematical exhibitions: Each group of thirty students in a district was encouraged to plan and conduct a mathematical exhibition in a select school, with the help of senior resource persons in mathematics.

(vi) Creative mathematics teaching sessions: Selective areas in mathematics were taught using participatory approach. The students were directly involved in the development of the lessons by the teachers. Five sessions were conducted in each group by a team of experts.

More details on the above six strategies are given in Appendix IV.

Conclusions

In view of the significant improvements noticed in the mean scores of each of the three affective variables, it can concluded that the six strategies together can be of significant help in developing the three affective outcomes in students. Although this experimental design is not precise enough to warrant a broad generalization, the strategies in combination can be recommended for use by teachers whose initiative is to develop the three affective outcomes tested in this study.

APPENDIX I

ATTITUDE SCALE

Some statements are given below to find out the attitude of children towards mathematics. Read the statements carefully and put a '✓' mark against each statement in the column of your choice.

A = Agree
N = No opinion
D = Disagree

No.	Statements	A	N	D
1	The time spent for learning mathematics is time well spent.			
2	I learn mathematics only because my parents compel me to do so.			
3	All pupils should do a large number of problems in mathematics on their own.			
4	It is a pity that children are forced to learn mathematics which is the most uninteresting subject in schools.			
5	There is no use in learning many of the areas in mathematics which have no practical meaning in life.			
6	There is nothing wrong if one reads other useful books when the mathematics class is in progress.			
7	Many of the developments in mathematics have no relevance in life.			
8	All children will be happy if they are allowed to play at the time the mathematics class is conducted.			
9	Children should be given as many mathematical puzzles and games as possible even during liesure time.			
10	One can earn a living even without learning mathematics.			
11	There is no need to give so much importance to mathematics in schools as is given today.			
12	We must banish mathematics from the class room.			
13	It is horrible to think of extra classes in mathematics when even the regular classes are boring.			
14	Children are to be taught mathematical games and recreational problems whenever time permits.			
15	Sports and games can do a lot more good when compared to mathematics.			
16	All children should work hard to get high scores in mathematics tests.			
17	All schools should have mathematics clubs.			
18	I feel very sorry when I am forced to skip a mathematics class.			
19	A person who has no knowledge of mathematics will be useless as a worker or a citizen.			
20	Mathematics is one of the most interesting subjects taught in schools.			

APPENDIX II

Mathematics Interest Inventory

The following series of questions are intended to identify your interest in certain activities. Three activities are given in each question. You are required to choose the one you prefer most and write down the letter (A, B, or C) representing your choice against the respective question number on the answer sheet provided.

1) A. Drawing geometrical figures using mathematical instruments
   B. Drawing cartoons
   C. Drawing portraits of great literary figures.

2) A. Making a garden in front of the house.
   B. Making solid models using cardboard.
   C. Making clay sculptures.

3) A. Collecting stamps from different countries.
   B. Collecting pictures of geometrical patterns.
   C. Collecting newspaper clippings of important political developments.

4) A. Reading biographies of mathematicians.
   B. Reading detective novels.
   C. Reading biographies of great politicians.

5) A. Become a member of the school mathematics club.
   B. Become a member of the school literary association.
   C. Become a member of the school social service league.

6) A. Helping to water the school garden.
   B. Helping to clean the classroom.
   C. Helping friends do mathematics problems.

7) A. Collecting old dresses for charity.
   B. Collecting different rocks for the school science museum.
   C. Collecting mathematical puzzles to conduct a mathematical competition.

8) A. Attending music concerts.
   B. Attending political party meetings.
   C. Attending a special mathematics class.

9) A. Witnessing the working of a computer center.
   B. Witnessing an art exhibition.
   C. Witnessing a boat race.

10) A. Making garments.
    B. Making delicious food.
    C. Making different patterns using a given set of geometric shapes.

11) A. Writing essays on modern literature.
    B. Writing essays on ancient culture.
    C. Writing essays on applications of mathematics.

12) A. Find different method of proving theorems.
    B. Find important places on the world map.
    C. Finding meanings of difficult words using a dictionary.

13) A. Completing magic squares.
    B. Completing crossword puzzles.
    C. Completing unfinished poems.

14) A. Listening to lectures in politics.
    B. Listening to lectures on mathematical developments.
    C. Listening to lectures on the origin of social customs.

15) A. Interviewing famous mathematicians.
    B. Interviewing famous dancers.
    C. Interviewing famous writers.

16) A. Write an essay on the discovery of America.
    B. Write an essay on the contributions of great mathematicians of our country.
    C. Write an essay on the achievements of science.

17) A. Identify difficult sections in the science textbook.
    B. Identify difficult sections in the mathematics textbook.
    C. Identify difficults words in the language textbook.

18) A. Understand the principles of geometry.
    B. Understand the principles of our constitution.
    C. Understand the principles of different religions.

19) A. Understand how an airplane engine works.
    B. Understand how engineers design buildings.
    C. Understand how mathematicians solve algebraic problems.

20) A. Know about the mathematicians who developed non-Euclidean geometry.
    B. Know about the great men who fought for our freedom.
    C. Know about the great explorers who traced the path of rivers.

APPENDIX III

Inventory for measuring the Value for the Power of Mathematics

Some statements about mathematics are given below. Read them carefully and express your acceptance of them placing a tick (✓) mark against the statement in the appropriate column of your choice.

A = Agree
N = No opinion
D = Disagree

No	Statements	A	N	D
1	Learning mathematics makes an exact man.			
2	Training in mathematics would help to develop logical reasoning.			
3	Mathematics is the only subject which trains children in systematic thinking.			
4	Learning mathematics would help to develop the ability of analytical thinking.			
5	Problem solving ability can be acquired through the study of mathematics.			
6	Learning mathematics would help a person do things with great speed and accuracy.			
7	By systematic learning of mathematics children acquire the ability to do other abstract forms of work.			
8	Mathematics is an important subject in school syllabus because it is the basis for learning many other subjects.			
9	By learning mathematics children acquire greater confidence in their work.			
10	Mathematics is the only subject which helps children develop to their full mental potential.			
11	Training in mathematics will help to develop perseverence.			
12	Mathematical symbolism has helped man make some of the great discoveries.			
13	Mathematics helps to study the interrelationships between different phenomena.			
14	Mathematics makes it possible to study the properties of large groups.			
15	Those who have recieved systematic training in mathematics will prove to be good in other fields as well.			
16	Nature is full of mathematical forms.			
17	Mathematical methods help to study other subjects better.			
18	All human beings make use of mathematics unknowingly in their daily life.			
19	The achievements in modern technology were made possible by the use of mathematics.			
20	One of the outstanding characteristics of science is its power of prediction, which it derives from mathematics.			

APPENDIX IV

Special Strategies Tested

1. Seminars on crucial conceptual areas in mathematics.

The students were made to participate in seminars on the following conceptual areas.

(i) Mathematical systems without numbers: A simple mathematical system based on the set of possible clockwise rotations of a square was demonstrated. The students were shown a square piece of cardboard with their corners and center labelled (leftmost panel of Fig. 1). The rotation about the center O in the clockwise direction were then defined as follows:

R_0 - Original position (rotation through 0 degrees),
R_1 - Rotation through 90 degrees,
R_2 - Rotation through 180 degrees, and
R_3 - Rotation through 270 degrees.

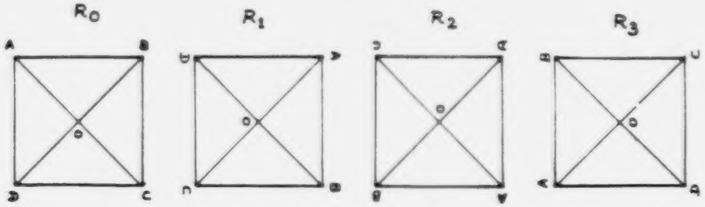

Fig 1: A square and its rotations about its center in the clockwise direction.

In this mathematical system the simple transformations - rotations - were taken as elements of a set and an operation '@' defined on them as follows.

$R_i @ R_j$ - A rotation of R_i followed by a rotation of R_j.

A table showing the results of this binary operation was formed and displayed to the students (Table 1). The students were then asked to compare the properties of this new mathematical system with the real number system (the infinite set of real numbers with the operation 'addition'). The students were encouraged to develop such systems with new elements.

Table 1

The @ operation on the elements of rotation.

@	R_0	R_1	R_2	R_3
R_0	R_0	R_1	R_2	R_3
R_1	R_1	R_2	R_3	R_0
R_2	R_2	R_3	R_0	R_1
R_3	R_3	R_0	R_1	R_2

(ii) Finite geometry in a six-point space: By developing a finite geometry dealing with a finite number of points, the students were shown how an abstract geometry can be developed. This finite geometry consists of a set S of undefined elements 'points' and 'lines'. The undefined relation is 'on' (contains). The following is a consistent set of postulates for this geometry.

Postulate 1: Each pair of lines in S has at least one point on them in common.
Postulate 2: Each pair of lines in S has no more than one point on them in common.
Postulate 3: Every point in S is on at least two lines.
Postulate 4: Every point in S is on not more than two lines.
Postulate 5: The total number of lines in S is four.

A model for this geometry can be represented by a diagram which is given in Fig. 2.

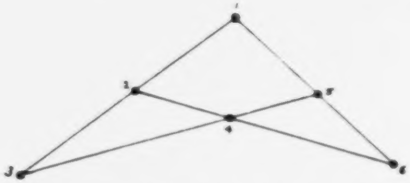

Figure 2: Diagram representing the six-point geometry.

Then the following theorems were stated and proved with the help of the diagram.

Theorem 1: There are exactly six points in S.
Theorem 2: There are exactly three points in each line.
Theorem 3: Each point in S has one and only one point parallel to it. (A new term 'parallel points' was coined. Two points are parallel if they are not on the same line.)
Corollary: On a given line in S, not containing a given point there is one and only one point parallel to the given point.

The students were shown that another system of geometry can be produced by changing the postulates.

(iii) An unusual algebra: With the help of some switches, pieces of wire and batteries, series and parallel electrical connections were demonstrated. Some models were constructed using these connections and the basis for Boolean algebra was developed. The similarity between an always open switch and '0' (in the usual algebraic addition), and an always closed switch and '1' (in the usual algebraic multiplication) was demonstrated. The students discussed the various other properties of this algebra and compared them with those of the usual one.

2. Directed library reading sessions.

Fifty selected books were displayed in the library. The books were selected to provide a wide spectrum of mathematical topics and applications. A short and simple description of the contents of each book was attached to its cover. The students were encouraged to read selected areas from at least four books. Instructors were at hand to provide guidance. The students took notes which they used in discussion sessions conducted at that time.

3. Lectures and demonstrations by mathematicians and educators

Opportunities were given to the students to get acquainted with some eminent mathematicians and mathematics educators. The students found the lectures on the following topics fascinating and inspiring.

(i) Kerala's heritage in mathematics - Dr. S. Parameswaran,
(ii) Recreational aspects in the study of mathematics - Prof. K. Karunakara Menon,
(iii) Applications of mathematics in social sciences - Dr. A. Sukumaran Nair,
(iv) Non-Euclidean geometries - Dr. K. Soman, and
(v) Computers in the modern world - Prof. Y. Kalyanasundaram.

The lecture on Kerala's heritage in mathematics revealed some extraordinary mathematical works done by mathematicians in the state of Kerala dating from the 15th to the 17th century which have come to light recently. Dr. Parameswaran talked about the ancient Kerala mathematicians and astronomers. He also related to some ancient works in which the quadrature of a circle and infinite series representing the ratio of the circumference of a circle to its diameter (pi, of course) have been discussed.

The lecture on recreational aspects in the study of mathematics was truly entertaining to the students. They actively participated in solving some of the puzzles, paradoxes and fallacies demonstrated during the lecture.

In his lecture on the application of mathematics, Dr. Sukumaran Nair emphasized that mathematics in one form or other is used by everyone, everywhere, knowingly or unknowingly. The students were made aware that without mathematics there cannot be any development in science and technology. Many examples were presented to show how mathematics is used in various disciplines and how powerful mathematics is.

The lectures in non-Euclidean geometry and on computers in the modern world were also well received by the students.

4. Conduct and reporting of mathematical projects by students.

To develop the creative talents in mathematics and to make aware of the power of mathematics, students were encouraged to do projects in topics of their interest. The resource persons helped the students in the project. The reports were exhibited in a separate section during the exhibition. The following are some samples from these projects.

A Correlated Study: One student collected the marklists of six classes in Standard X and did statistical analysis on them, by preparing the frequency tables for each class and subject. The student also prepared visual aids like histograms, frequency curves etc. He was able to arrive at certain conclusions on relative performance of the students from the correlation values obtained.

A Square Model: A student took a square and divided it into 9 equal sub-squares. Then the sub-squares were classified according to the number of other squares they touch on their sides. The total number in each class is then counted. For the 9-square case,

Number of squares touching four other squares = N4 = 1
Number of squares touching three other squares = N3 = 4
Number of squares touching two other squares = N2 = 4
Total = N4+N3+N2 = 9

When the large square was divided into 16 squares (4x4) the numbers in the above classes were N4=4, N3=8, N2=4, which add up to 16. Extending this to 25 squares, N4=9, N3=12, and N2=4. The student was then able to form a general relation. If the large square is divided into nxn then

$$N4 = (n-2)^2, \quad N3 = 4(n-2), \text{ and } N2 = 4$$

Thus the total n^2 can be written as

$$n^2 = (n-2)^2+4(n-2)+4$$

or replacing n by x+2

$$(x+2)^2 = x^2 + 4x + 4$$

which is a well known algebraic relation.

5. Organizing mathematical exhibitions.

The students made models of many geometric solids, made patterns and posters displaying matheamtical principles under the skillfull guidance of some teachers. The students then exhibited their works in an exhibition organized for this purpose which was open to the public.

6. Creative mathematics teaching sessions.

In these sessions the students were given opportunities to think and develop new ideas and construct geometrical models, patterns, generalized formulae atc. Specially trained teachers guide the children to work on their own and prepare learning aids and devices. Some examples are given below.

Model construction: Using pieces of cardboard and sticky tape the five regular polyhedra were made. The patterns shown in Fig. 3 were drawn on the cardboard pieces and then cut out and folded to form the solids.

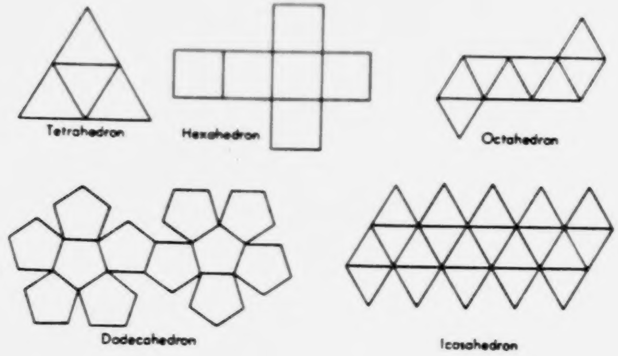

Figure 3: Patterns used in making the regular polyhedra.

Construction of regular polygons and patterns based on them: The students were shown how to construct regular polygons with various number of sides (Fig. 4). They also experimented with various polygons in different combinations to make mosaics such as the one shown in Fig. 5. The students learned to draw other geometric patterns like the 'mystic rose' (Fig. 6) as well.

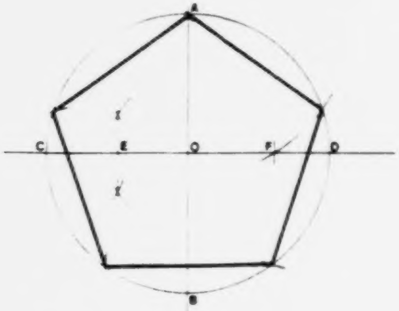

Figure 4: Regular pentagon construction.

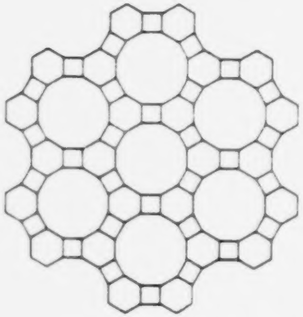

Figure 5: A sample mosaic formed with regular polygons.

Conics from circles and lines: With the guidance of the instructors, the students constructed parabolae, ellipses and hyperbolae as shown in Fig 7. They learned to construct these conics by folding a point drawn on a piece of paper to points on a line or a circle on the same piece of paper (Fig. 8). They were fascinated to see that the creases produced by the folding formed tangents to the conics.

An instrument to draw parallel lines: The students used cardboard strips and thumb tacks to construct the simple instrument shown in Fig. 9 to draw parallel lines.

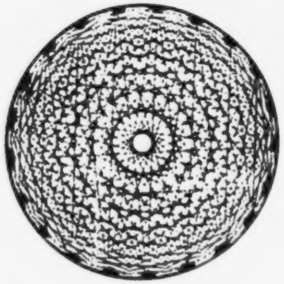

Figure 6: The 'mystic rose'

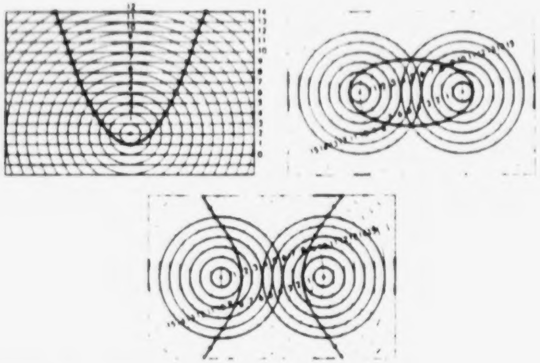

Figure 7: Construction of conics.

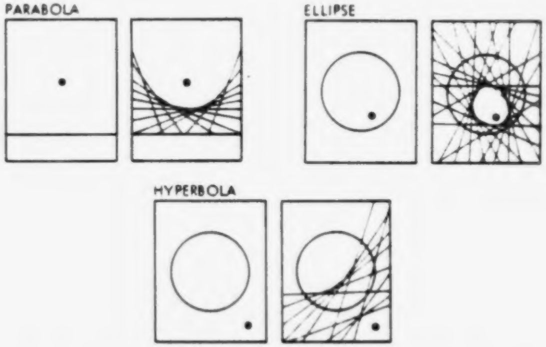
PARABOLA
ELLIPSE
HYPERBOLA

Figure 8: Construction of conics by folding paper.

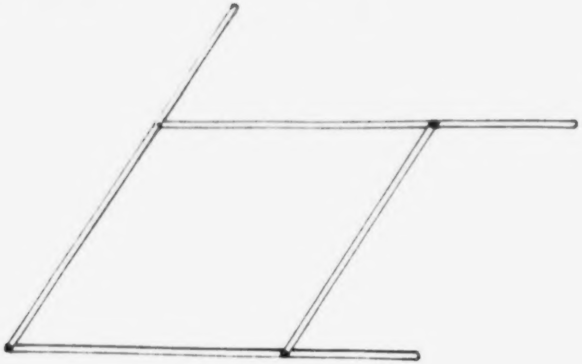

Figure 9: A simple instrument to draw parallel lines.

A SOCIAL CONSTRUCTIVIST ANALYSIS OF CLASSROOM SCIENCE TEACHING

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Introduction

This paper describes a pilot study in which the curriculum and instruction of three science teachers is analyzed from a social constructivist perspective. Our interest in this analysis is based in part on concerns about limitations of the conceptual tools available within the conceptual change research tradition for the analysis and improvement of classroom science teaching.

Out of the large body of conceptual change oriented research, relatively few studies document the successful use of conceptual change research to analyze or to improve classroom science teaching. Most studies have focused on cognition of individual students rather than on teaching and learning in classroom settings. The use of conceptual change research to improve teacher education has been especially problematical. Most successful classroom studies have depended either on specially developed curriculum materials (Anderson & Smith, 1987; Roth, 1984) or on the abilities of teachers who were themselves active researchers (Minstrell, 1984; Nussbaum & Novick, 1982). In short, the conceptual change research tradition has not developed strong programs of classroom research or practical classroom application.

Some of the difficulties that have presented the development of a strong classroom research program lie in characteristics that are central to the conceptual change research tradition, particularly its emphasis on analyzing the scientific thinking of individual students. Researchers have generally had to rely on methods developed by teaching effects researchers (cf. Brophy & Good, 1986; Doyle, 1986) or educational ethnographers (cf. Erickson, 1986) for observation and analysis of classroom teaching while developing conceptual change analyses of student learning. While research done in this manner has produced valuable insights, both data collection and data analysis tend to be forbiddingly complex. The results of such research may also be messy and inelegant, since the classroom observation techniques were developed by researchers with quite different interests and theoretical orientations from conceptual change researchers. The practical application of such complex and messy research in classrooms is and will remain a formidable task.

Cognitively oriented classroom research would be stronger if we could develop cognitively oriented methods of analysis that somehow encompassed both the social processes of classroom teaching and the thinking of individual students, helping us to see clearly the relationships between the two. One source for such analytical methods is research conducted in a social constructivist tradition (cf. Anderson, 1987b; Rogoff & Lave, 1984; Vygotsky, 1962, 1978; Wertsch, 1985).

Researchers in this tradition have focused for many years on the processes of learning in a social context. In particular, Vygotsky and others have shown how Piaget's insight that thinking processes are often internalizations of overt actions can be extended to speech and other social behavior. Thus, Vygostky describes our thoughts as internalizations of speech patterns encountered and practiced initially in social situations, including classrooms.

Thus, a social constructivist perspective predicts that under the proper conditions (discussed below) students will internalize patterns of speech and action that they encounter in science classrooms. An analysis that focuses on this process has a potential for the power and elegance that comes from a unified perspective on classroom processes and student thinking.

This is a pilot study in which we attempt to explore the potential of a social constructivist perspective on teaching and learning by using it to develop a simple system for observing and analyzing science classrooms. The results suggest some interesting and important substantive questions about these and other science classrooms. We feel that the results also demonstrate the potential and some of the limitations of this research perspective.

Methods

In this section we first describe the development of two research questions that provided the framework for the study. We then describe how those questions were used to guide classroom observations and analysis.

Conceptual Basis for Research Questions

The analyses reported below were guided by two research questions. One focused on curriculum: What was being taught and learned. The other focused on instruction: How it was being taught and learned. Our objective in each case was to develop questions that would help us to see how patterns in classroom discourse might be internalized by students, thus becoming patterns in student thinking.

Developing a curricular question. The current cognitive literature is full of attempts to characterize what students know about science or what they learn in science classes. Student knowledge and learning are described in terms of conceptions, alternative frameworks, schemata, frames, psychological primitives, and so forth. None of these serves the purpose of the present study, however, because they all describe knowledge in terms of cognitive states or structures that are internal to individual students. For the purpose of this study, we wished to define the curriculum in terms of "patterns of speech and action" that occur in the classroom and that can be internalized by individual students.

In describing individual thinking as derived from speech and other forms of social behavior, we are departing from the individualistic orientation that characterizes most conceptual change research. What we do, however, is in accord with long standing practice in both social constructivist psychological research and the philosophy of science. Consider, for example, the following passage from Toulmin (1972):

> The content of science is, thus, transmitted from one generation of scientists to the next by a process of *enculturation*. This process involves an apprenticeship, by which certain explanatory skills are transferred, with or without modification, from the senior generation to the junior.
>
> . . .
>
> Described in these terms, the proof that an apprentice scientist has grasped some concept of his science is evidently tangible and 'public.' For he demonstrates his ability to apply the concept in a relevant manner, by solving problems or explaining phenomena using procedures whose 'validity' is a communal matter. This demonstration yields not so much circumstantial evidence from which we draw conclusions about the apprentice's 'private' mental grasp indirectly, by speculating inferentially about an hypothetical 'inner life' on which his publicly demonstrated skills depend. More crucially, his explanatory achievements provide the most immediate and direct confirmation possible that he has grasped the significance of the concept, i.e. its current role in the relevant discipline.
>
> . . .
>
> In a Cartesian mood (it is true) we might be tempted to say that in acquiring the essentially mental concept, "energy," the apprentice also learns--quite incidentally--to express his grasp of this concept, by performing the associated public calculations and observations. But that would be to miss the point. In the case of communal concepts, any "inner" or "mental" activities are secondary and derivative; learning to perform the relevant collective activities is the indispensable thing. However rich the apprentice's inner life may be, if he is unable to give any tangible demonstration of his conceptual grasp, we can dismiss his understanding of the term "energy" as--at best--sketchy and impressionistic. (pp. 159-160)

In studying science classrooms, we are also watching an enculturation process, in which students are being encultured not into a small professional community of scientists, but into the (hopefully) much larger community of scientifically literate adults. Therefore, our analysis of the curriculum in the classrooms that we observed started with a question about scientifically literate adults: How do they demonstrate publicly that they have grasped the explanatory powers of science? What do they do with their scientific knowledge that is socially valuable and that convinces others of their understanding of science? Our

current answer to these questions involves four different types of activities: *description*, *explanation*, *prediction*, and *control* of natural systems or phenomena. Those activities are discussed below.

1. Description. We often use scientific knowledge for purposes that are essentially descriptive in nature: providing names for things, or measuring them, or classifying them. The ability to provide accurate or "correct" names, descriptions, or measurements of natural systems or phenomena is one characteristic of a scientifically literate adult.

2. Explanation. Toulmin, in the passage quoted above as well as in his other writings (cf. Toulmin, 1961, 1972) emphasizes explanation as a primary goal of science. We acquire scientific knowledge and develop theories because we want to explain how the world around us works. As Toulmin argues above, we could hardly consider a person to be scientifically literate if he or she cannot use scientific knowledge to explain natural phenomena.

3. Prediction. The ability to generate predictions is a key test of the validity of a scientific theory as well as an important use of scientific knowledge. Thus, scientifically literate adults often use their scientific knowledge to generate predictions about future observations.

4. Control. Control of natural systems and phenomena is more a function of technology than of science *per se*. Scientific knowledge, however, plays an essential role in the development and use of technology, and much of the justification for the teaching of science in our schools concerns the development of technological competence, or competence in dealing with technological issues, among workers and citizens.

A couple of characteristics of the activities listed above are noteworthy. First, all four activities are what we normally describe as "applications" of scientific knowledge (though this analysis and others lead to questions of whether the knowledge can exist independently of the application). Second, all humans engage in description, explanation, prediction, and control of natural phenomena, not just scientifically literate adults. Much of the research discussed in this conference describes how children and adults who are not scientifically literate engage in these activities. Naive descriptions, explanations, predictions, and attempts to control the world are generally less precise and accurate, less coherent, and not based on accepted scientific theory.

Thus, enculturation into the community of scientifically literate adults could be viewed as a process of learning to describe, explain, predict, and control the natural world[1] in ways that are more precise, more coherent and more in accord with current scientific theory. This leads us to the curricular question that guided this study: *How did teachers and students in the observed classrooms engage in activities characteristic of scientifically literate adults: description, explanation, prediction, and control of natural systems and phenomena?*

Developing an instructional question. A great many activities take place in a typical classroom, and students clearly do not transform all of them into internal thought patterns. This only happens some of the time. What, then, differentiates between actions that are internalized and those that are not? How must students encounter and practice a particular activity in order to achieve individual mastery? Researchers working in the social constructivist tradition have developed at least partial answers to these instructional questions.

These answers are based in large measure on empirical work that was not done in classroom or laboratory settings. Instead, social constructivist researchers have focused on teaching and learning as they occur during the everyday activities of life and work in a variety of cultures, such as language learning by American toddlers (Greenfield, 1984), Mexican Indian girls learning traditional weaving (Greenfield, 1984), and the apprenticeship experiences of Liberian tailors (Lave, in preparation).

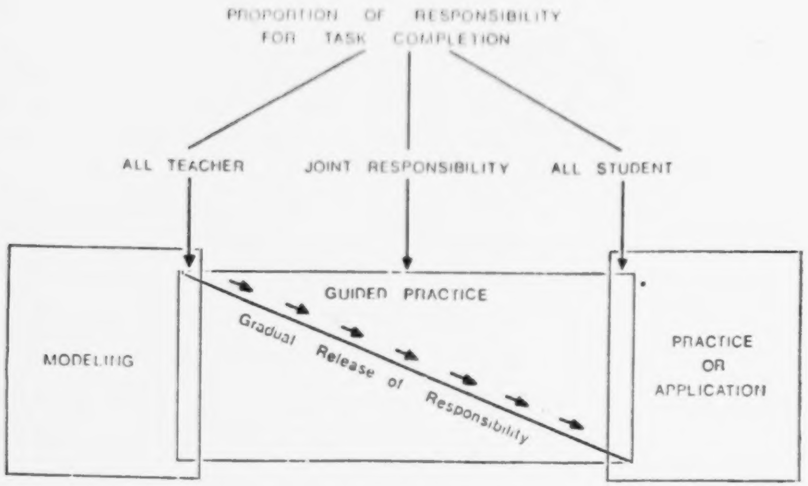
An essential insight coming from these studies is that what Wertsch (1985) calls "goal-directed actions" are often performed not by individuals, but by pairs or groups of people. Some of the members of those groups may initially be incapable of performing the actions, but through participation in the groups they learn to perform functions that were initially the responsibility of others.

This is particularly true when activities are carried out by groups that include both people who have already mastered the activity (teachers or masters) and people who are ready to learn (students or apprentices). Even if their primary intention is something other than teaching (such as "playing together" or "getting the job done"), ordinary people are often successful teachers when they work or play with willing and able learners. The process by which this successful teaching and learning takes place is portrayed in Figure 1 (from Pearson & Gallagher, 1983). It is described by Collins, Brown, and Newman (in press) as consisting of three basic steps: modeling, coaching, and fading.

In the first step, modeling, the activity is done entirely by the teacher and observed by the students. The modeling of an activity can be successful only if a couple of conditions are met. The first of these is what Wertsch (1985, following Rommetviet, 1985) refers to as "establishing intersubjectivity." The teacher and students must have a common understanding of the nature and purpose of the activity being modeled. A second condition for successful modeling is that students must actually observe the teacher doing the key steps of the activity. As Collins, Brown, and Newman (in press) point out, this condition is rather easily met for overt psychomotor behavior. It is much more difficult to meet for activities such as reading comprehension or problem solving, where many of the key steps

Figure 1

Strategy for Building Task Mastery
(from Pearson & Gallagher, 1985)



involve covert mental operations. For such activities, the teacher must find ways of making those covert mental operations explicit and open to observation by students.

During the coaching phase, the teacher and students share responsibility for task completion as the teacher helps the students to master the activity for themselves. The teacher can help students to perform the activity in both proactive and reactive ways. Proactive support, often labeled scaffolding, occurs when the teacher structures the activity for students or performs certain key steps, allowing the students to operate within the framework that the teacher provides. The teacher can also support students reactively, by monitoring their performance and intervening to correct errors or suggest improvements.

Fading, the final stage in the instructional model suggested by Collins, Brown, and Newman, occurs as the teacher provides less and less support to students as they do the activity, ultimately allowing them to do it without support from the teacher.

This three-stage model of instruction provides the framework for the second research question: *How did teachers and students in the observed classrooms engage in modeling, coaching, and fading?*

Procedures for Classroom Observation and Analysis

This was a pilot study, conducted in three classrooms. The first was a kindergarten classroom; the other two were high school biology classes. All three teachers were mentor teachers in the Academic Learning Teacher Education Program at Michigan State University. They were selected as mentor teachers partly because they had outstanding reputations as teachers who helped their students to master academic content.

Each classroom was observed by a single observer. The three observers, the co-authors of this paper, were first-year teacher education students assigned to the mentor teacher that they observed. Two observers were undergraduate juniors; the third was a post-graduate student. Observations were conducted regularly during winter and spring terms of 1987 at intervals of once or twice a week.

Observers did not use a formal structured observation system. However, the four authors of this paper met about once a month to discuss and focus their observations. Initially, observations were guided simply by our intention to use a social constructivist framework like that of Collins, Brown, and Newman (in press) to analyze what was happening in the observed classrooms. Over time, the two research questions described above were developed to focus observation and analysis:

1. How did teachers and students in the observed classrooms engage in activities characteristic of scientifically literate adults: description, explanation, prediction, and control of natural systems and phenomena?
2. How did teachers and students in the observed classrooms engage in modeling, coaching, and fading?

Case Studies

This section contains summaries from field notes of the classes taught by the three teachers, who were given the pseudonyms of Ms. Allen, Mr. Brown, and Ms. Collins. Ms. Allen was a kindergarten teacher; Mr. Brown and Ms. Collins both taught high school biology. Development of the summaries was guided by the two research questions listed above.

Ms. Allen

Ms. Allen taught a kindergarten class of 22 students. The students participated in many hands-on learning activities, with little time devoted to traditional "play" time. Ms. Allen, who has a science background, had science lessons at least three times a week and often every day of the week. During these science lessons/activities Collins, Brown, and Newman's cognitive apprenticeship model of instruction (modeling, coaching, and fading) was coupled with the activaties of description, explanation, prediction, and control to provide a framework that helped the observer make sense of and evaluate the teaching and learning which occurred in the kindergarten classroom.

Of the four activities, description was the most frequently and precisely practiced. During my field observations (once every two weeks winter term and twice a week spring term), I observed the students involved in a variety of description-oriented tasks. The students usually began by describing phenomena in broad terms, then increasingly narrowed and refined those descriptions. For example, the students went through a refinement of description while learning about animal movement. As they progressed through a unit on animal movement, the students initially described total body movement: Birds fly, bunnies hop, fish swim, and horses run. Ms. Allen then began to model and coach descriptions that specified mechanisms: Birds fly by flapping their wings, fish swim by moving their fins, and so forth. These descriptions were always teacher-directed. The instructor did a great deal of modeling, especially when the students were describing objects for the first time. As the students became more adept at describing, Ms. Allen coached their performance through the use of probing questions and encouragement. There was a high degree of student-teacher interaction as the teacher modeled and coached and the students responded appropriately. Fading did not occur initially, yet toward the end of the observations, an increase in fading was noticed, as the students independently carried out descriptive activities for extended periods of time.

While explanation was frequently practiced by Ms.

Allen, the students rarely participated in activities which required their explanations of phenomena. When the students were required to explain, their descriptions often served as the bases for their explanations. For example, when the students were asked to explain how various animals move, all the student replies were based on the descriptions which the students had previously generated: Birds fly because they flap their wings, fish swim because they move their fins, and so forth. Ms. Allen modeled this process of using known information to generate an explanation. She also coached the students in their attempts to explain observed phenomena. In general, teacher modeling of explanations was quite intensive, coaching occurred less frequently, and fading was not observed. I would like to observe higher elementary classrooms to see if more coaching and fading occurs during student explanations at that level. Perhaps the lack of emphasis on independent student-generated explanation is due in part to the descriptive and exploratory nature of the kindergarten science curriculum.

Prediction was the second most frequently practiced activity in the kindergarten classroom. Every day the students made predictions during calendar time. During calendar time, for instance, the students discussed the day of the week, the month, the data, and the weather for that day. Initially, as the students made predictions about the date, day of the week, and month, there were many incorrect replies as the students did not understand what their predictions should be based on and were only able to make guesses. However, as the teacher modeled and coached predicting behavior, student performance improved. The modeling took place as Ms. Allen shared her thoughts aloud with her students, "When I want to know what day of the week it is, I think about what yesterday was. If yesterday was Monday and tomorrow is Wednesday, then today must be Tuesday." By the end of the year, the students had become

very adept at correctly predicting the month, day, and date. The teacher had almost completely faded, returning to coaching only when remediation was required. By the end of the year the students were also learning to make predictions related to subject material in science, such as what will happen when two magnets are placed next to each other. The teacher modeled and coached heavily; little fading had occurred by the end of the year as the students were still exploring the process of making predictions during science lessons.

Control was the activity least frequently practiced in the classroom. I did not observe control being modeled, coached, or faded. I do not know why control was not a part of the science curriculum. I would be interested in looking at the development of this activity across the grades.

Throughout my observations, I noted a great deal of teacher-student interaction. Especially prominent was the extent of modeling and coaching: Ms. Allen extensively modeled and coached every day in a variety of lessons. The activities of description, prediction, and, to a lesser extent, explanation were also prominent features of the classroom.

Mr. Brown

Mr. Brown taught three high school biology courses: Human physiology, zoology, and media biology. The media class is designed for remedial and special education students. It parallels the zoology course, but at a slower pace and it is more student-centered. These three courses are offered as second term options for first year biology students. The choice allows students to focus on an area that most interests them and provides them with a strong grounding in that area. Although all three classes were observed, most of the examples below come from Mr. Brown's zoology course.

As with most biology classes, there was a strong emphasis on describing the structure and function of living systems. This, combined with the ever-present push for content coverage, led this teacher to place much more emphasis on description and explanation than on prediction and control. Thus some important uses of biological knowledge, predicting responses and controlling living systems, were overshadowed by the immediate goals of describing what is seen and explaining its function.

This emphasis can be seen in an analysis of the classroom activities. The students had many opportunities to see how description is used in biology and to practice it themselves. For example, the zoology students were introduced to a more sophisticated description of insect than the one they had previously relied on. Rather than defining an insect as anything small which crawls, the teacher showed them that insects are described as having certain characteristics such as three body parts and compound eyes. He spent a considerable amount of time outlining these characteristics and helping the students develop a set of notes. As he lectured, he would ask them questions which could be answered using these notes. This kind of coaching and scaffolding could also be seen in the review sessions. Rather than telling the students the characteristics of insects as he had in lecture he had the students tell him. If they needed to refer to their notes they could, but with the realization that the less they needed the support the better. The review was followed by a test where the students had to list the characteristics on their own. This process of the teacher modeling a description, followed by coaching and supported student use of the description was typical of many of the classes observed.

It is important at this point to make a few comments. Although the students were coached in the characteristics of insects, they had limited opportunities to use them to describe actual insects. Mr. Brown's normal practice was to have a laboratory exercise in which students used the characteristics they had studied to describe actual specimens. I was not present, however, for the lab on insects.

The students also had many opportunities to see how descriptions of structure and function were used to explain biological phenomena. For example, the teacher used the description of the reproductive system of frogs and the nature of external fertilization to explain the close proximity of the male and female frogs during mating. In this case, although the teacher modeled the explanation for the students, they did not practice giving the explanation themselves. This particular lesson was late in the year and there was considerable pressure to get through the material. In general, the students had fewer opportunities to write out or verbally express explanations. In a compromise between the time such participation would take and the need to monitor students' understanding, Mr. Brown relied on short answer responses, which he would then elaborate to form complete explanations. Thus, explanations were modeled more than they were coached and faded, the students had fewer opportunities to internalize the teacher's explanations.

While the classes included much description and some explanation, there were fewer times when prediction was used. The class where Mr. Brown asked the students to think ahead and make predictions the most often was the media class. Perhaps this was because these students required more help in developing connections between the concepts. For example, after the media class had studied Platyhelminthes and Nematodes, he asked them to predict what the nervous system of the Annelids would be like. To help them he coached them through a review of the systems in the two phyla and reminded them of the trend of increasing complexity and organization that they had been observing. Although he was only looking for them to say that the system would be more complex, he was actively modeling the thinking behind the material they were studying. This is in contrast to the zoology class where he presented the systems as facts and expected the students to form connections on their own. He did mention that they should think back to the earlier phyla, but he did not model as explicitly the connections by encouraging them to predict the characteristics. For most classes besides the media class, the students did not often see Mr. Brown engage in prediction or have the chance to make predictions from their understandings.

As in Ms. Allen's class, activities involving the control of phenomena were rarely observed. Mr. Brown usually mentioned control only in passing to provide a reason for studying biology. For example, the teacher told the students that nematodes are studied because they are often parasitic and spend part of their life cycle in the solid wastes of animals. Infection could occur if humans came into contact with untreated wastes. When the students were tested, however, they were asked only to describe the life cycle of the worm. Thus, the test question focused on description rather than control. There were no questions about how nematode populations or their effects on humans could be controlled. Since they were not asked such questions, the students could not be coached in developing this skill for themselves.

The classes observed offered students an introduction to some aspects of scientific reasoning, but it is clear that Mr. Brown and other biology teachers must make some difficult curricular and instructional choices. Because of the emphasis on structure and function, the students had many more opportunities to model and be coached in description and explanation than in prediction and control. Although the students were coached in description and explanation, they often had only one chance to do an activity with coaching before they were tested. Thus, Mr. Brown's teaching fell short of the ideal instructional procedure described above in which students gradually increase responsibility for their performance. By shortening the lengthy process of coaching and fading, Mr. Brown was able to cover more content, but probably at some cost to the depth of his students' understanding. The balancing of the desire to have students really understand the content with the press for content coverage creates a set of difficult choices for Mr. Brown and other science teachers.

Ms. Collins

Ms. Collins teaches biology in the same high school as Mr. Brown. She was observed teaching classes in genetics and human physiology. The examples used in this case study come from the physiology class, particularly from the unit on the respiratory system.

Ms. Collins is an experienced teacher, having taught for about ten years, and she has been actively involved in projects to improve the quality of science teaching. Her teaching in the observed classes incorporated much of what she has learned from those projects. She taught through a combination of lecture and discussion, getting the students actively involved from the beginning of each unit. She also included several labs in each unit and allowed the students opportunities to use the knowledge and understanding they gained in her class.

Especially in human physiology, description was probably the most prominent activity. It is essential to know the structures and functions of the human body in order to understand it, and there are enormous numbers of structures and functions in the human body to observe. Ms. Collins, knowing this, devoted much of her teaching to description. In each unit, she began with in depth models of good, scientific descriptions of structures and functions. As the unit progressed, she coached the students as they made comparable descriptions. She faded this support (sometimes at different rates for different students) until the end of the unit, when they were expected to be able to scientifically describe structures and functions covered in the unit.

For example, at the beginning of the unit on respiration, Ms. Collins explicitly described the mechanics of breathing (inhaling and exhaling) in scientific terms. As she stood in front of the class, showing herself breathing, she discussed how the movement of the diaphragm affects the air pressure in the chest cavity, thus causing air to flow in and out of the lungs. She emphasized that specific terminology and processes (diaphragm movement) must be included in an accurate description of breathing. As the unit progressed, she led discussions that required students to describe respiratory air movements in a variety of situations (laughing, crying, hiccups). She used probing questions and reminders to coach them to use specific scientific terms and to refer to diaphragm movement, air pressures, etc. in their descriptions. She gradually faded this support; near the end of the unit she gave the students homework questions that required descriptions of breathing and air movements and labs in which they described their own breathing. As she faded, she still used some guidance questions to indicate specific points that should be included in their descriptions. For the test, they were expected to be able to offer scientific descriptions of respiratory air movements in all the situations that were discussed.

With the emphasis in biology on structure and function, it is no surprise that the explanation of function of body systems was the second most prominent activity in Ms. Collins' classes. As with descriptions, Ms. Collins modeled, coached, and faded to help her students develop scientific explanations of functions.

For example, Ms. Collins introduced the idea that breathing rate was controlled by the level of carbon dioxide in the blood, then modeled how to use it as a reasonable explanation. She thought aloud as she reasoned through how carbon dioxide levels can control breathing rates. Throughout the unit, she coached them to develop scientific explanations using carbon dioxide levels to account for different breathing rates in different specific situations. She faded her help until she required students to offer comparable explanations of situation-specific breathing rates at the end of the unit.

Prediction was not as common but was included in most units. Ms. Collins taught this activity in the same way as the others. For example, she thought aloud to model as she reasoned through what she knew about breathing rates to predict breathing rates in specific situations. She then coached them as they attempted to predict breathing rates in new examples. In the end, she expected them to predict breathing rates in several realistic situations. For example, how does exercise in gym class affect your breathing rate, and, thus, you?

Control was the least commonly practiced activity, yet Ms. Collins managed to include it in most units. Once again, she used modeling, coaching, and fading to teach this activity. For example, she modeled control by thinking aloud as she decided how she wanted to affect her breathing rate, predicted what would affect it in that way, and set up a situation to consciously control it. She coached them in controlling their own breathing rates in a series of labs, using relaxations, exercise, and hyperventilation as activities to vary their carbon dioxide levels consciously. She faded her support throughout the unit. To conclude the unit, she required them to set up situations to achieve a desired effect. For example, she asked how they could control their carbon dioxide levels to increase the length of time they could hold their breath (which is useful for swimmers).

Throughout my observations, Ms. Collins incorporated all three steps of the cognitive apprenticeship model in her teaching, but not necessarily in equal amounts. She generally modeled and coached a great deal in her units, then faded support quite suddenly, holding the students responsible for the desired responses. Like Mr. Brown, Ms. Collins was, at least in part, responding to time pressure. With the pressures to cover specific topics in a class, the amount of time devoted to each unit was limited.

As for the view of science presented by Ms. Collins, description and explanation were the predominant activities. She also included prediction and control as important features of most units. All of those activities are important parts of science in the real world. The emphasis, however, is different. The predominant activities of classroom science were description and explanation of structures and functions. The primary activities of adult science, on the other hand, involve prediction of responses and control of natural phenomena.

Conclusion

Three issues are addressed in this final section. First, some patterns that are apparent in the case studies are discussed. Second, implications of the framework used in this paper for the practice of science teaching and teacher education are discussed. Finally, we describe some ideas about how the social constructivist and conceptual change research traditions could be integrated in a program of research on science classroom teaching.

Discussion of the Case Studies

Although an exploratory study like this one does not support definitive conclusions, several interesting patterns and problems are evident in the case studies reported above. At the curricular level, it is interesting to note that the description-explanation-prediction-control framework could be applied successfully to classrooms as diverse as kindergarten and high school biology. We hope that using these categories of activities will help us to see curricular relationships among various levels of science teaching that are not apparent in analyses using more traditional categories.

Another interesting curricular pattern concerns the relatively heavy emphasis on description and lack of emphasis on control in all three classrooms. The emphasis on description may be an artifact of the classrooms selected; kindergarten students are heavily engaged in learning to describe what they see around them, and biology is the most descriptive of the sciences taught in high school. On the basis of our experience, however, we would judge that the lack of emphasis on control is characteristic of the science curriculum in general. This is an interesting finding in light of a current tendency to advocate science education as a solution to the lack of technological literacy in our workforce or our citizens (cf. National Commission on Excellence in Education, 1983). It seems reasonable to question whether our science curriculum can deliver what is implicitly being promised.

It is also clear from these case studies that the emphasis on extensive content coverage in the high school biology curriculum confronts teachers like Mr. Brown and Ms. Collins with a difficult instructional dilemma. It is impossible to do an adequate job of modeling, coaching, and fading for the many activities that they are expected to include in the curriculum, so they must choose between failing to cover the assigned topics and failing to follow through the process of modeling, coaching, and fading. It is not surprising that teachers often choose the latter option,and that may in fact be the best choice. Much of the research on the persistence of student misconceptions, however, indicates that students often need large amounts of modeling, coaching, and fading to master scientific topics. More extensive research that includes assessment of student learning would help us to decide when, and how much, modeling, coaching, and fading is necessary for students to master particular activities.

Implications for Practice

There is considerable consensus among the people attending this conference about some of the changes that need to be made in the science curriculum and instructional practice in American schools. Most of would agree, for example, that we should generally teach fewer topics in greater depth, that teachers need to help students see what is wrong with their own ideas about phenomena, and that students need more opportunities to apply scientific ideas in a variety of contexts. Making these changes, however, cannot be the work of a few researchers attending a misconceptions conference. Instead, these changes must be the work of thousands of teachers, materials developers, and methods instructors, most of whom do not have training or experience in conceptual change research.

A program to improve practice in our profession as a whole must be reasonably clear and simple in conception and execution. It also needs to be evolutionary rather than revolutionary in nature, building on and growing out of present practice. As we argued in the introduction, it is difficult to see how current conceptual change research can serve as the basis for a program of practical change that has these qualities. The framework used for this study, however, is relatively simple and easy to connect with present practice. We have found it useful in curriculum development projects (cf. Anderson, 1987a) and in science methods classes as well as for the present study.

The activities of scientifically literate adults (description, explanation, prediction, and control) have proved useful as a framework that unites curricular objectives, instructional activities, and evaluation. Students in a methods course, for example, can see how a particular activity (such as explaining how carbon dioxide level controls breathing rate) can be the basis for an instructional objective, for a set of classroom activities, and for test questions. It is much more difficult to use misconceptions or alternative frameworks for these purposes.

Similarly, the instructional model of modeling, coaching, and fading is very useful for helping students to think about what it means to "teach" something. Prospective teachers using this framework are much less likely to give a lecture, assign some homework, and decide that they are done with a topic. The framework also helps them think productively about their roles as teachers and their expectations of their students at different stages in the teaching process.

Developing a Program of Classroom Research

We have tried to show in this paper how a social constructivist framework can provide simple and elegant analyses of problems that are difficult and complex when analyzed using other approaches. In particular, the framework used for this study helps us to see clearly a pattern of relationships among the activities of scientifically literate adults, the school curriculum, the social processes of classroom teaching, and the learning of individual students.

This framework can also be used, however, as the basis for a research program that explores the real complexities of classroom science teaching. Many of those complexities are associated with problems of task analysis. What are the essential elements of a "good" explanation of how we control our breathing rate, for instance? What cognitive resources must students draw on to produce such an explanation? What difficulties will students encounter when they try to explain phenomena associated with breathing rate? Teachers need answers to these questions in order to do a good job of modeling and coaching, one that focuses on the true sources of students' difficulties. Other important problems concern task difficulty and sequencing of tasks. Which activities are so simple that modeling, coaching, and fading are not necessary? Which are the most difficult? How should a teacher or curriculum developer decide what activities to include in a unit, and in what order?

It is clear that conceptual change research on student cognition can help us to answer questions like those above (for an example, see Anderson, 1987a). Thus, conceptual change research on student cognition can be integrated into a social constructivist analysis of classroom science teaching. A research program based on the combined analysis could produce important new insights into the classroom teaching and learning of science.

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FOOTNOTES

[1] This certainly is not a complete list of the important activities of scientifically literate adults. In particular, it omits activities associated with the acquisition of scientific knowledge or the development of new knowledge. These activities might include learning from text or other sources of information, developing new knowledge through observation or experiment, and developing knowledge by reasoning about the relationships among observations, concepts, and theoretical principles.

Interview Studies in Teacher Education: Examples from Extraordinary Contexts

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Recently, Phillip Morrison (1987) addressed science teachers at the 1987 NSTA convention in Washington, D.C. He spoke of the fundamental process of naming things and illustrated his remarks with the example of 'milk.' Certainly the vast majority of the human race learns a name such as 'milk' at the very onset of speech, its referent presenting no ambiguity. Yet not all infants nurse successfully on human milk and nutritionists have given us "soy milk." In what sense is "soy milk" true milk? Is secretion from mammalian milk glands critical to the concept of milk or simply incidental? Is a protein composition -- within certain limits -- the key? Does "milk" primarily name our sensory perception of a class of liquid substances -- including that poured from a coconut -- which appear cloudy? Or is milk defined by the nourishing function it performs?

Morrison used this example, I believe, to illustrate the nature of true understanding of a concept, understanding that comes from deep familiarity with the object of interest. Milk is no simple substance, and the creation of soy milk as a substitute reflects deep understanding of what 'milk' means. As Morrison points out, cheesemakers have an understanding of milk. They would not readily accept soy products as cheese -- is "tofu" analogous to cheddar?

Experts -- whether food scientists or craftspersons -- have very sophisticated understandings of milk. Yet the last meaning for 'milk' suggested above -- based upon "nourishing function" -- strangely ties an operational abstraction to what an infant child probably understands, in a dramatically important way, when first associating relief from hunger with milk.

There are two (at least) subtle points to make from this reflection on Morrison's talk. First, for a common concept, scrutiny reveals within it many layers of unsuspected meaning. These "layers of meaning" interact with close observations of the phenomena the concept attempts to capture. Secondly, within the most primitive grasp of the concept lies an embryo of sophisticated insight. These two subtle points carry a very significant message to teachers: temper the urge to treat science concepts as easily defined, precise categories of thought. The corollary to this message is to respect the embryonic thoughts of children.

Consider a few related examples of the problem of "concepts being deeply layered with unobvious meaning." There are wasps that partially digest plant fiber with their saliva, then construct a delicate nest from this mixture -- thus had the insect world invented 'paper' eons before people thought of writing down their thoughts. Children, however, have difficulty accepting a wasp's nest as being made of true paper. Even stranger than the realization that paper wasps do make paper is the thought that lava fills the oceans. Romey (1983) has discussed the instructional potential of the water-magma analogy in detail. Afterall, any good rock composed of crystalline minerals (such as the mineral 'ice') becomes a lava, in the jargon of geology, if it exists at the surface of the earth in a molten state. Other bodies in the solar system may have sulphur oceans or methane icebergs. These uses indicate not the error of everyday thinking but the evolution of a category to encompass new knowledge of events in terms maintaining some bridge to the familiar, even at the price of silliness when old and new usage sit side by side.

There is a disturbing trend in the "misconception tradition" emerging at many places in the field of education. This disturbing trend treats children's knowledge as naive and incorrect, then seeks to prescribe tactics that will diagnose and dispel these misconceptions efficiently. The problem with this misconception of the misconception tradition is that it wholly ignores the inherent power in any child's reflective thought and the essential, never completed, restructuring of a teacher's knowledge in response to attempting to see the world through a child's mind.

There is no activity equal in potential to individual interviews for communicating this view of science learning to teachers. Preparing the interview engages the teacher in examination of his or her own presuppositions about the subject. Conducting the interview demands skillful restraint in pressuring for right answers and sensitive incorporation of children's thought and language into subsequent questions. Evaluating the interview transcript -- in the context of feedback from peers and instructor -- inevitably encourages reevaluation of what children's utterances actually meant.

Interviewing techniques and contexts as course assignments range widely. One way of assessing their claimed value is to inspect interview results from extraordinary contexts: 1) on the concept of a shadow with teachable mentally retarded (IQ below 50) children, 2) on the explanation of rainfall given verbally by hearing-impaired pre-adolescents, and 3) on the actual understanding of a museum sound-travel exhibit by a tiny sample of both children and adults. The following sections of this essay describe three such interview studies completed by teachers in graduate level (master's degree) science courses.

Grass makes the shadow grow longer

Is science instruction useful in the education of teachable mentally retarded children? The teacher who introduced the shadow task and interview to such children believes so. For these children, grasp of the concept of time contributes to useful independence. Shadow length is visually simple and a direct indicator of time. Where does an inquiry about shadows begin for a group of children labeled mentally retarded?

According to the teacher, study begins with establishing which shadow belongs to whom. After settling this matter, the task turns to observing shadows after intervals of time selected by the teacher. In this case, children stood outdoors and observed their own shadows at 9:15 a.m., 11:15 a.m., and 2:15 p.m.

Only notes exist reconstructing the dialogues between the teacher and students. On an individual basis, each child responded to questions such as, "Tell me about your shadow. Where is your shadow now? Is your shadow the same? Has your shadow changed?"

One of the six children in this group noticed the change in shadow length and associated the sun in the sky with the existence of her shadow.

Several, however, explained change in shadow length once made aware of this phenomenon through questioning. Half voiced belief that a shadow changes length "because it's on grass." There was, as it turned out, some confusingly similar variables. As the day wore on, shadows shifted from pavement to grass. Longer shadows fell on the grass.

Here exists an example of human reasoning at the borderline of conceptual understanding. The child has invented a causal explanation inadequately constrained by notions of grass and light and the hypothesis suggests appeal to an emergent mental model of real world events. What had the teacher learned from this exercise with her students?

To paraphrase her in-class remarks, the experience "reminded me to watch for and control misleading variables, then introduce one at a time and discuss the problem it creates." This approach and its assumption that instruction helps students construct mental models ran, in her view, counter to the prevailing wisdom of special education as implemented in the schools through IEPs (individualized educational plans).

These plans define learning in terms of behavioral outcomes and tend to reduce teaching to operant conditioning, yet the goal for mentally-handicapped children remains the same -- maximum independence. For this teacher, a small interview assignment cracked the behaviorist armor, now no longer trusted as the only or even an appropriate strategy to follow in pursuit of this goal.

When the cloud melts, it rains

Many problems of grammatical construction and semantic anomaly plague efforts to interpret deaf children's conceptualization as expressed in an interview context. In the following case, a deaf teacher shared interview results

from questions posed to a sample of eight students from an eighth grade, hearing-impaired, earth science class.

When asked, "What are clouds?" the words "fog" and "cotton" appeared in several responses:

- The clouds look like a fog up in the sky.
- They are cotton but some of them become heavy and start to rain.
- They are light and white. Sometimes they become fog and start to rain.
- They are white things or big puffballs in the sky.
- The clouds are foggy and looks like cotton. They lay on the sky.
- Clouds are made from evaporating.

The phrase "lay on the sky" is an instance of unusual semantics. The "become fog, look like a fog, become heavy" utterances stand in contrast to mention of "cotton, light and white, big puffballs." The distinction lays in the association of rain with fog and fog-like clouds as opposed to a notion of clouds without rain. One student associated clouds with evaporation, but the interview failed to probe whether the student realized that clouds were water droplets.

When asked, "What makes it rain?" many responses included nearly metaphorical phrases:

- Sun shines. The wind helps blowing and it evaporates. Then it changes into water vapor and makes into the cloud. The clouds move and fall down to the ground.
- The sun makes evaporating from lakes, rivers, and

streams; and carries to the cloud. Then it starts to rain.

- The clouds become full and let the rain go.
- The clouds make it rain.
- The cloud is melting, that makes it rain.
- The clouds become dark and then rain because of having positive and negative charges.
- Water vapor from clouds make and become full. Then they start to fall down to the earth's crust.

The common thread is these answers is that rain happens when clouds become full, yet the variations on this theme are perhaps more interesting: clouds which "fall down or melt." Perhaps these children are demonstrating how to stretch concepts to encompass phenomena adequately despite a paucity of verbal labels. The sharp, sometimes awkward grammatical constructions belie a sensitive, creative expression of conceptual understanding. In truth, much rain in temperate latitudes does begin as ice and to speak of rain as "falling clouds" counts as an error only if arbitrary, ad hoc stipulations are invented to separate water droplets into "rain" and "cloud" categories.

In summary, clouds do melt and fall. How many teachers have pushed their own grasp of rainfall to an understanding of physical mechanisms for making cloud droplets grow larger? Without such a mental model, rainfall from foggish cotton is mysterious and a key connecting link in the water cycle remains open to versions of the "filling up" explanation of rainfall. More importantly, the language of the deaf teaches us to play with non-standard constructions in order to tease apart and reconstruct the nonverbal conceptions upon which they rest.

When the tube bends, the sound slows

In a recent science education course devoted in part to analyses of learning in informal contexts and taught at the Oregon Museum of Science and Industry (OMSI), one interview assignment paper earned attention from an exhibits director. The nearly immediate consumption of this piece of student work clearly underscored the value of interview insights. Interviews can dovetail with any number of research and evaluation strategies assessing visitor reactions, understandings, and appreciations of informal science learning opportunities. Interview interaction with the visitor does skew the spontaneous, predominantly recreational experience of musuem-goers, but often provides the only valid insight into just what interpretation the visitor has made of the exhibit message.

At OMSI, there is a "Sound Tube Exhibit." It consists of 235 feet of red tubing resembling a vacuum cleaner hose wrapped around the ceiling of the physical science exhibit hall. The two ends of this tube dangle at visitor level, enticing interaction. When used to best advantage, a user speaks into one tube, then hears his or her own voice through the other, delayed by a noticeable fraction of a second.

Often visitors do not know what to do with the tube. Usually they speak into one tube while a friend listens to the other. There are many qualities about the sound that change as it travels through the tube. Most commonly, visitors are simply pleased to hear a soft, audible voice transmitted around an often noisy room.

The time delay may or may not receive notice. Twenty visitors of mixed ages agreed to answer the teacher-interviewer's questions. Thirty percent made no mention of "vibrations in air" when asked to explain how the sound went around the tube. Half "reported that the corners caused the sound to slow down," according to the student's report to the class. Despite several verbal and pictorial cues, not one of twenty visitors grasped the key principle of the exhibit: a demonstration of the speed of sound in air. Repeatedly, visitors explained how sound "slows down" when "going around corners." One elaborated with an analogy:

- Bouncing off the corners causes it to lose speed, like a ball.

In the words of the student who conducted the interviews, "Almost everyone used analogies to explain how the sound behaved." The use of analogy presupposes the existence of one mental construction whose relationships can be exploited to render a novel situation intelligible. The "bouncing" analogy carries the price of the image of an object loosing kinetic energy through collisions. Sound energy does dissipate (a phenomenon the analogy properly captures) but sound speed is a function of the density of the air which transmits the vibrations.

The study of actual visitor understanding at this simple physical science exhibit suggests a dilemma to pose in order to encourage conceptual change: Imagine two trumpets. One is straight. The other is coiled. All other properties of the tubes are the same. If blown equally hard, would sound leave each one at equal speeds? In fact, the student who conducted this study closed his paper by suggesting that the museum post just such playful questions.

How different is the reasoning of the intelligent adult on a visit to OMSI from that of the mentally-handicapped child who investigated shadows? There appears to be one profound similarity: both achieve insights unconstrained by concepts of presumably related phenomena, the grass surface in the case of casting shadows and the curving wall of the tube in the case of sound propagation. There are certainly many differences. One of significance ought not escape our attention: the mentally-handicapped child, with guidance, correctly perceived the event. (The shadow changed.) The intelligent, verbally proficient adult did not.

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STRATEGIES TO IMPROVE THE TEACHING OF MECHANICS USING COMPUTER SIMULATION

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This work deals with the use of computers in the teaching of Physics. On this field a considerable amount of work has been already done and a wide literature is available (1,2,3), but we are far from reaching the objective pointed out by Roman Sexl: "Our aim is to make all possible mistakes about the use of computers in science as fast as possible..." (4).

At the University of Pavia we have been carrying out research in this field since 1981 with the aim of finding strategies which could be effectively applied in different stages of the teaching learning process. In summarizing our steps we will briefly mention how our attention switched from simulation of phenomena to simulation of experiments while we were developing different instructional strategies.

- Simulation of phenomena: the packages we produced belong to the area of dynamic computer graphics, and include interactive graphics programs dealing with collision phenomena (5) and wave propagation in an elastic medium (6). They are meant to support a standard course of Physics devoted to first-year University students. At this level the traditional teaching generally involves three stages: presentation of the theoretical framework, classroom exercises, and a laboratory activity where simple experiments are carried out. It is often difficult to blend these stages harmoniously and one of the consequences is that the theory receives little feedback from experiment. Our packages were designed to bridge the gap between theoretical framework and laboratory activity. We employed a didactic strategy using a tutorial dialogue based on simulations that allow one to visualize details of motion which usually escape observation and which present physical situations (such as the switching between reference frames) that are usually only verbally described. The dialogue allows students to answer questions and to take appropriate measurements, and guides them to construct the mathematical description of the phenomenon they are studying. The program controls the choices of the student and comments on them, giving her/him individualized help. Whenever it is possible, for example, the physical situation corresponding to the answer of the student is simulated. In such a way s/he can recognize mistakes and easily arrive at the correct answer.
- Simulation of experiments: the didactic strategy we have proposed (7) requires that interactive

graphics programs be used by students jointly with an intensive laboratory activity. We called our strategy "packlab strategy" because the computer package employed in it is designed and used in connection with the planned laboratory activity.

The work of students is organized in three phases:

1) observation and analysis of experiments which introduce the topic to be studied

2) running of computer simulations

3) carrying out laboratory experiments.

In phase 1 students look at simple experiments showing how the phenomenon, presented in a theoretical way in the lecture and in textbooks, has correspondence in the real world. These experiments must be designed in such a way that they direct the students' attention to the phenomenon rather than to the operation of the experimental set-up. (The student should obtain, in this phase, a kind of intuitive, qualitative understanding of the subject). Phase 1 could be enriched by the use of a good Physics film, presenting experiments that may be quite complex. The students should note differences and similarities among the apparatuses used in the classroom and those presented in the film. The comparison should allow them to become aware of practical constraints and limits of the observed experiments.

In phase 2 the students analyse computer simulations of the experiments considered in phase 1. The aim of this activity is to give students the chance of analysing in depth the model of the accepted physical interpretation of the phenomenon and to encourage the comparison between this model and the qualitative understanding they obtained in phase 1.

Phase 3 requires the personal involvement of students in laboratory work so that they can experience the difficulties of taking measurements in a real experimental situation and of drawing from them significant results. This experimental activity is carried out when the students are already familiar with the subject and have recognized the problems connected with it. In this way it should be easier for them to play an active role in the laboratory.

An example of the "packlab strategy" is a unit we developed for high school students dealing with the motion of freely falling objects. We chose this topic, a classic one in Newtonian mechanics, because a test we had carried out with students in introductory Physics courses, using questions culled from the literature, showed that the topic is not well understood by the majority of students, although it is studied in every high school.

Since a first trial of the package with a limited number of students showed that it is an effective tool to illustrate the composition of horizontal and vertical motions in free fall, we were encouraged to go on and to consider other aspects of the learning process for the problem of falling bodies. We were also convinced that a proper use of simulations could help students in focussing their attention on their own thinking and in comparing their explanations with accepted physical theory.

On the belief that this comparative action could be enhanced by analysing the process of theory construction, we designed a new didactic strategy based on joining computer simulations with the history of Physics. It stresses the reconstruction of historical experiments and their analysis. Our aim was to explicate the pattern of reasoning which inspired the design of the original experiments in order to guide students in comparing their reasoning with the model underlying simulations.

- Simulations of historical esperiments: computer simulations of original experiments, in our opinion, can help students to understand the evolution of an idea in an active way, enrich the reading of original sources and illustrate the pattern followed by a researcher in his work. The dynamic display of images offers learning opportunities which could not be obtained otherwise, for the essential parts of an experimental apparatus, and the working of every part of it can be advantageously visualized. It seems particularly useful and interesting for students jointly to analyse simulations of an original experiment and of a modern version of the same experiment.

Of course the use of computer simulation cannot substitute for students' laboratory experience: skills and knowledge which they can gain in a laboratory are very different from those which the use of computer simulations provides. But in the case of historical experiments, the original set-up and even the original "research environment" can be reproduced (difficulties and obstacles included), and students, by running computer simulations, can take advantage of facilities usually denied in a normal laboratory.

Simulations should be planned in such a way as to suggest the conceptual framework guiding researchers to design experiments and to arrange apparatus. By offering hints for proper choices and plans for explorations the direct involvement of students can be obtained.

Following the above guidelines we have prepared a package for students in introductory physics courses. It includes computer programs and guides which contain a historical section with relevant original sources. The simulations reproduce the experiments that Galilei carried out with an inclined plane, in a sequence that seeks to respect the chronological order as reconstructed by S. Drake (8). It appears also to be the most convenient sequence to allow students to discover how the different quantities are related to each other. While in the simulations of Galilei's experiments students' attention is focussed on kinematic aspects of the fall of objects, the simulation of Atwood's machine requires that students consider the complex causal framework of Newton's dynamic interpretation of motion.

Finally the simulation of modern equipment helps students to recognize how the difficulties Galilei and Atwood had in measuring instantaneous velocity can be overcome today, by using accurate timers and/or oscillographs.

The last two strategies we described have been tested with a limited number of students and under our direct control.

We are in the process of testing our packages on a larger scale in order to evaluate their effectiveness and to gather information about the best use of the strategies. But already they look promising to reach complementary goals. Crucial is the way teachers will use our materials, how they will introduce the work we propose into normal teaching.

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Teacher Beliefs About Science and Their Influence on Classroom Practice

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Teachers' philosophical beliefs about science and science teaching have an impact on classroom and laboratory instruction. Two student teachers and their supervising teachers were interviewed to assess the nature of their beliefs and the way in which these beliefs affect classroom instruction. The beliefs of the student teacher and the supervising teacher were probed to determine similarities and differences. The extent to which beliefs were changed or compromised to allow for differences was influenced by the student teachers' and supervising teachers' views of their roles.

One of the frustrations of educational research is that the results of research endeavors are seldom incorporated into the classroom. Perhaps one reason is that new practices are determined not by researchers, but by classroom teachers who act on arguments which may or may not be influenced by research findings. Fenstermacher (1986) wrote:

> The relevance of research for teaching practice can be understood as a matter of how directly the research relates to the practical arguments in the minds of teachers.

In an effort to understand how teachers construct their practical arguments, and then act on them, a study of teachers' beliefs about their content area and teaching becomes valuable, since these beliefs guide the teachers' decisions in classroom instruction.

Thompson (1984) found that teachers' beliefs about the nature of mathematics and teaching mathematics affects the way they teach. The teacher in her study who considered math to be primarily a tool of the scientist emphasized applications of mathematical concepts. The teacher who viewed mathematics as a continuously expanding and changing discipline created a more open classroom atmosphere and encouraged students to guess and conjecture when solving problems. Another teacher who believed the content of mathematics to be "cut and dried," with little opportunity for creative work, focused on teacher demonstration of mathematical procedures, followed by student repetition of these procedures.

Lantz and Kass (1987) studied the relationship between science teachers' beliefs and the implementation of new curriculum material. Beliefs and values concerning high school chemistry, teaching, students, and the school setting were found to influence the teacher's interpretation of the new curriculum. They found that the three teachers who used the same basic chemistry curriculum taught very different lessons about the nature of science due to differences in their beliefs and values.

Cooney (1985) examined the struggle of a beginning teacher whose beliefs about mathematics and mathematics teaching conflicted with student expectations and curriculum. The teacher believed that mathematics *is* problem solving and that having the students work fun problems would be successful and motivating. Although his approach was accepted by the more advanced students, the general math students did not like it and viewed it as "playing around" rather than real mathematics.

Studies with beginning teachers are particularly important because they provide information regarding the stability of the beliefs and values held by teachers once in the classroom. Crow (1987) found that preservice teachers enter the teaching profession with a set of beliefs about the attributes that make a good teacher. These beliefs are created on the basis of their prior experiences. The teacher education program may influence or contradict these beliefs. In the two cases in which a serious conflict arose between the preservice teachers' beliefs and instruction in the education program, the teachers dropped out of the program. In the two cases in which serious conflicts did not arise, the preservice teachers were found to adopt aspects of the education program which were congruent with their beliefs and either forgot or dismissed topics which were not compatible with their beliefs. Although there were occasions during the student teaching experience in which the teachers' beliefs were challenged, their images of their roles as teachers endured.

The implementation of instruction consistent with teachers' beliefs is particularly interesting under the special constraints of the student teaching experience. Student teachers may perceive a need to conform to the supervising teachers' desires. A recent review compiled by Griffin, Hughes, Defino, and Barnes (1981) concluded that student teachers' attitudes, values, and/or philosophies will often shift toward that of their supervising teacher during the student teaching experience.

Purpose

This study was designed to gather preliminary information on the beliefs of student teachers and their supervising teachers about science and science teaching and to examine the impact of these beliefs on classroom instruction during the student teaching experience. The interaction between the supervising teacher's beliefs and those of the student teacher was probed to determine the extent to which the student teachers' beliefs were compromised or suppressed to cope with conflicts.

Method

The student teacher/supervising teacher pairs participating in this study were selected upon the recommendation of their university supervisor because she believed that the teachers would express different philosophies. The teachers were sent a list of questions (see Appendix) prior to the interview so they could think about the issues in advance. Each of the teachers was interviewed separately for about 45 minutes.

Coverly/Nately

The student teaching experience took place at a high school in a medium-sized mid-west town containing a large research-oriented university. The students are mostly from families associated with the university, resulting in an unusually stimulating, but competitive environment. Grades are very important to the students and their parents. (Residents sometimes refer to the high school as the town "junior college.") The supervising teacher, Coverly, teaches introductory, accelerated second year, advanced placement, and mainstream chemistry classes using a wide variety of textbooks. Since Coverly teaches only chemistry classes in an unusual environment, disciplinary issues were not of primary concern and therefore were never mentioned.

Coverly

Coverly has been teaching chemistry at this high school for two years. Prior to this time he taught chemistry and math in a small town school district in another part of the state. Although he began his teaching career 12 years ago, this was his first opportunity to work with a student teacher. He is in his mid-thirties and has a bachelor's degree in chemistry from a small college and a master's degree in education from the local university.

Coverly believes that science is a way of looking at things - a process of explaining why something happens. He believes that alchemists were not scientists because they merely discovered facts without explanation. However, the phlogiston theory was science because it was an attempt to explain observations.

> ...it was not necessarily the best of science ... but they were trying to explain the world around them. They were looking at the phenomenon. They were trying to come up with explanations for why things worked. Now just because they had a wrong explanation does not mean it's not science.

Coverly believes that science is a way of approaching a subject area.

> ...you try and find all the facts you can and you try and organize those into a coherent theory and then test that theory to see if it does explain things ... that's to me is the science.

To him testing the theories is a continual process. As new facts are discovered, they have to be integrated into the theory. Sometimes the theory must be discarded. When new theories are proposed they must explain the old facts. The net result is that a new theory explains more and more simply. Coverly does not teach this explicitly, but does teach it implicitly by illustration when talking about the development of the atomic theory.

Coverly believes that science probably is both created and discovered. Laws are discovered whereas theories are created. He brings up the question of whether math is created or discovered and decides that geometry is "for the most part created." Coverly believes that science is similar to history in that both contain a large body of facts. One of the major ways in which science is different from other disciplines is that it is quantifiable and therefore more testable. Although psychologists may try to quantify their theories, Coverly is unsure of the degree to which they have succeeded in doing this. He does not think that psychological theories are as testable or as valid predictors as the theories in the hard sciences. Furthermore, statistical studies in psychology using large samples are not valid when applied to an individual event. If psychology can reach the point of quantifying its predictions, then it could deserve to be called a science. Coverly believes that science is quantifiable, testable theories.

Coverly places a great deal of emphasis on quantification. He believes it is one of the primary reasons for having students perform laboratory experiments.

> So our purpose in lab is to reinforce generally the material covered in the ... non-lab part of the course, as well as ... a strong quantitative basis. The students have to get used to using equipment and finding and recording ... quantitative numbers and dealing with those. It's not just observations, it's also obtaining weights, volumes and dealing with those.

Coverly felt that science might change very much in the near future. However, his major concern is the information explosion and how more theories could be put into a high school course. Since most of his students go to college, he is very concerned about the body of knowledge the colleges expect from their incoming students. He also believes the public expects a certain body of knowledge. Coverly feels constrained by these expectations and wonders how he as a "teacher and a scientist," can keep up with the facts.

The constraint of keeping up with the increasing body of knowledge influences the kinds and numbers of lab activities in the course. (His classes do about seven labs per semester.) Coverly does not feel that they can take the time required for what he calls "discovery labs." Furthermore, he believes that a much larger amount of material can be covered in lecture than in lab.

Coverly states that his interpretation of the message of science educators is that process is very important. However, he believes that a combination of facts, theories and process are important because objectives vary. In other words, Coverly's beliefs override what educators may tell him is important.

Nately

Nately completed all course work for certification to teach chemistry and math at the local university. His university supervisor described his greatest strength as his thorough understanding of chemistry. He is attractive, personable and athletic, characteristics that likely contribute to his perceived excellent rapport with his students. He entered the teaching profession because he cares about people and believes that he can be influential in their development. He loves science and believes it can teach critical thinking in a way that will be beneficial to the students regardless of their career goals.

He describes science as follows:

> I think that science is a way of thinking ... you have to look at things in a critical sense. It's not just looking at something and saying this is black and this is white ... it's a critical sense in that you have to look at a problem and a lot of times you don't know how to solve it ... you can't just approach a problem from one point of view. Science is looking at it one way and if that doesn't tell you what you want to know, ok, fine, you back up, you think about it a minute and you approach it from another point of view.

Nately says apologetically that "science is not pure" and that what is being taught now is not necessarily the gospel. For this reason, he will not use the word "fact" in class.

He illustrates the influence of this view of the nature of science on classroom instruction by describing a discussion with his students on the 105 degree bond angle of water. The introduction of the topic included a molecular orbital rationale for why the bond angle is 105 degrees. The following day, he brought to class a paper in which three scientists use different arguments for explaining the bond angle. He argued that even though the initial explanation was valid, it wasn't the only way to explain it. Similarly, in problem solving Nately encourages students who can't work a problem in a particular way to try another approach, by breaking the problem up into pieces and then putting it back together. "And no one way is the true, pure way to do something."

Nately's view of science is one of constant and often drastic change.

> I say ... some day we may come up with something that blows all this away and we've gotta start all over. But when we start all over, its gotta explain everything in the past plus this new thing.

The current research being carried out by NASA and nuclear chemists and physicists is likely, he believes, to produce radical change. Perhaps this is the reason why he seems rather unconcerned about coverage. He never mentions it. The fact that he has not had complete responsibility for a course from curriculum development to instructional implementation may also shelter him from feeling the pressure for coverage perceived by Coverly.

The Interaction of Coverly and Nately

Nately viewed his student teaching as a fabulous learning experience which greatly increased his confidence in his abilities. I would describe this practice teaching experience as successful, even though the beliefs of Coverly and Nately about science are somewhat different. Nately never speaks of facts, but sees science as critical thinking and problem solving. Coverly, on the other hand, believes that facts, theories, and process are all important aspects of science which must be taught. Coverly emphasizes quantification whereas Nately does not. Nately believes that we attempt to explain things in terms of mathematical formulas, but that it may not always be possible. Coverly views theories as right or wrong whereas Nately makes no judgment of right or wrong.

In spite of such differences in beliefs, the student teaching experience was remarkably harmonious. I believe this may be explained by the absence of dogmatism of both teachers. Rokeach (1970) describes dogmatism as a closed cognitive system which does not allow compromise and fosters intolerance. Coverly is neither dogmatic or authoritarian. Therefore he does not impose his beliefs on Nately.

Nately is competent and confident. When both were teaching, Nately used Coverly as a role model, to some extent. However, Coverly let Nately take over fairly early, leaving Nately without a role model. Since Coverly believed Nately to be capable, Nately had considerable freedom.

I asked Coverly what his expectations of a student teacher were prior to the experience.

> I expected someone to come in who was reasonably well-versed in the subject matter, that was used to planning things out in detail, and perhaps was a little apprehensive, but could begin to handle a classroom of kids.

He expected weaknesses in practical details like timing. He would not expect a student teacher to have a feel for the amount of time certain classroom activities require. Coverly felt that Nately was competent in the subject, was capable of planning a lesson, and could handle a group of kids and was therefore unafraid of giving him responsibility.

Coverly believed that he and Nately had similar philosophies about science, which was judged to be somewhat optimistic. (He attributed this to the fact that they had been educated at the same university.) However, Coverly also said that he thought it was rather difficult to make such a judgment because Nately was asked to teach only structured segments, which is very different from being told "here, you teach chemistry." Nately's philosophy should be more apparent when he is fully responsible for a class and has to make textbook and curriculum decisions.

Nately recognized some disagreement in philosophy, but it was not perceived as a major problem. There was some pressure to conform, but some conforming is necessary.

> ... you're walking into a strange environment where the students are used to one system, one type of teaching, and if you come in and change everything on 'em, it's not going to be a very positive experience for the student.

When Nately was asked if there were changes that he would have liked to make but could not, he said he would make changes in the curriculum; for example, spending time on organic chemistry in the first year course and including more kinetics in all the courses.

Cathcart/Flume

This student teaching experience took place in a middle school located 5-10 miles from a midwestern town of about 75,000. Most students come from blue-collar families who work in town and live either on the outskirts of town or a short distance away. Cathcart, the supervising teacher, uses the Silver Burdett *Intermediate Science Curriculum Study* (*ISCS*) in his seventh grade general science class. Cathcart has no other preparations.

Cathcart

Cathcart is in his late 40s and began teaching history at the same rural school 20-25 years ago. Although certified to teach social studies and science, he is currently teaching only general science. An impressive frame, about 6'3" and 250 lbs., contributes to his authoritarian image.

Cathcart believes that science is a process, i.e. the scientific method, which is an exact procedure. Psychology, according to his beliefs, is not a science because "it's very difficult to go in with a set of procedures as scientists use and get the same results again and again." He believes that this process is the most important thing he can teach his students because it is "a great approach for anything you want to look at," including personal problems. The scientific method can help them pinpoint the real question which needs to be examined.

Cathcart believes science progresses by obtaining more exact information.

> ... as we fine tune and refine our measurements and observations and theories, the theories of science will be changing.

Scientists are able to build on what has been discovered previously because of the "preciseness" of science which is due largely to mathematics. This building process is important because it makes it unnecessary to repeat everything that's been done before once those things have "been repeated enough to be proven." One of the problems in psychology is that the foundation is rather nebulous, making the building process difficult.

Cathcart believes that much of what is taught today is not really true. Cathcart equates accuracy with "truth."

> ... really half of what we teach today is not true. For example the moon is not exactly 240,000 miles, it's some exact number.

Cathcart says the problem is that we don't know which half is correct. Consequently, we should teach the scientific method, how information is obtained, and how it changes. Thus students will be prepared for change when it comes.

> But what we need to teach is [that] science is ... [an] exact procedural way of finding answers. The answers themselves will change as we get more information. And that's a healthy situation.

Cathcart teaches the scientific method by having the students study the steps and having them perform experiments using those steps. Because of the students' lack of solid math skills, he does not expect them to come up with exact answers in the experiments they perform. However, the procedures they follow and their "attitudes" are very important. He is more concerned with how they get the answer than the answer itself because it tells him whether they understand the process of science.

Cathcart believes that science is sometimes created because scientists occasionally create unstable isotopes and new organisms via genetic manipulation. However, scientific theories are mostly discovered. He is particularly fond of the school's current curriculum, ISCS, because the children actually make discoveries. (For example, the students make a thermometer.) To him, this ability to make discoveries is one of the major differences between science classes and classes in other disciplines. It makes science more tangible than other fields of study. Since grammar was created, he does not believe it is as logical as science.

> There's no rhyme or reason, it's just man decided to make a verb conjugate whatever a verb conjugates, where in science it's a logical process based on the scientific method.

He further believes that science is important because it makes students aware of their environment so that they may become more opinionated about how better to protect and use the environment.

Cathcart believes the role of creativity to be more important in science than in other fields.

> It's hard to be creative when you study history because all those things have been researched - everything there is to know is known.
>
> I think it's very important that creativity be encouraged and developed rather than stifled because it's those creative people who become the really obsessed science student.

Cathcart is pleased that this year they have learned to identify "creative" students. This is what they call the "gifted and talented" program.

Cathcart believes that some of his most important functions as a science teacher are to interact with the students, answer questions, and help the students develop questions. He is disturbed that the students have no questions. One of the ways in which he has dealt with this he has been working with the resource person in the library to write questions from which the students may choose and try to find an answer. An example is "Can man live on Jupiter?" He believes that this activity was largely an outgrowth of his philosophy of science.

Cathcart discussed the importance of three teacher attributes: ability to enforce discipline, emotional strength, and knowledge of content. Discipline in the classroom was a recurrent theme in the interview. Cathcart describes the students as quite different today than when he did his student teaching. Today they question authority in the classroom and may be involved in drugs and alcohol. Many come from broken families. Because students have changed so much, discipline is very important.

> There's no way on earth, Nancy, that you can teach if the class is either talking or even thinking about something else. As I sit here and talk to you, you're not gonna hear a word I say if you're thinking about something up on that shelf above your head or my head. It's just the way things are.

Cathcart believes that emotional strength is a very important teacher characteristic.

> There's a lot of stress. And I think one of the keys is when you leave the building at 3:00, at 3:15 ... you're no longer involved ... and many people can't do that.

Students will say anything, and a teacher must learn to not be bothered by student comments.

Content knowledge is not as important as discipline enforcement and emotional strength. A teacher can always find the knowledge needed.

> I mean you can learn, I've done it many times, when you're given a book and says "teach this book" ... so you read ahead ... you can compensate for lack of knowledge, but you cannot compensate for emotional immaturity.

Flume

Flume is a young female student teacher from a small town in the midwest who has just completed the coursework required for certification to teach general science. She says she has always wanted to be a teacher. This aspiration was further encouraged when she became a counselor.

> It was such a high to be in the center of attention. It's an ego trip.

Flume also cites a desire to help people as being important in her decision. She believes she has a lot more to offer than do many teachers in the field. She was influenced to teach science by reading about the shortage of science teachers and believed being certified to teach science would enhance her marketability. She has also been inspired by reading about the activities that good teachers use in teaching science.

Flume believes science is discovering why things happen the way they do and that this curiosity is a very important attribute for a scientist. When asked if scientists were more inquisitive than people in other disciplines, she gave the following response:

> ... no, I think they're about the same ... of course scientists want to go further ... because he's more inquisitive about his environment.

Flume would like to see curiosity in her students as well and is rather discouraged that they lack this inquisitiveness. Because of the importance she places on curiosity, Flume emphasizes discovery activities. She wants them to discover on their own rather than read in the textbook.

One of the ways in which history is different from science is that history cannot disprove theories the way science can. The statement of a historical hypothesis in a textbook or by a teacher is considered proof.

> ... in science they have proved that things either do happen or they don't happen and they change their theories ... it's just theories until it's proven wrong. It's like a corollary, a theorem or anything in math. It's true until it's proven wrong ... Where history you can say well, this is your observation ... but you can't really prove your hypothesis. It's proven by the fact that it's in the book or the teacher said so and that's how it's proven.

When Flume was asked if the book and the teacher are more of an authority in history than in science, she said no. At this age, what is in the text is taught as the gospel truth. It is not until college or graduate school that one can question science and prove it wrong. The purpose of the discovery activities is for students to discover and prove the hypotheses in the book.

Flume believes that psychology is a science because it follows the scientific method.

> I think psychology is a science because it is involved with ... it's all those four steps ... you make your observations, you record your data, you make your hypothesis and then you prove your hypothesis.

Flume believes that one of her most important jobs as a junior high science teacher is to "turn them on to science." Since this is their first science class, it is imperative that they leave it with a positive feeling. She recalls not liking her seventh grade science class. Flume believes discovery activities are important because they can excite the students about science. (Typically, discovery activities are done once per week.) The kids have fun with them. She notes, however, that discovery activities open up the possibility of discipline problems.

> But when you do these activities, they abuse it, and 'cause of discipline. You would not believe how things have changed. It's different out there than it was ten, twelve years ago, five six years ago ... the kids are different and unfortunately we can't do

> a lot of discovery activities because the kids go crazy.

Interaction of Cathcart/Flume

In this case, the interaction is much more complicated than in the previous pair. Cathcart is very authoritarian and for the most part, Flume submitted to that authority. The ISCS curriculum was followed very closely, so less of the instruction was chosen by Flume than by Nately. Flume describes the following situation:

> ... when I student taught ... I just did what he did. He says that works. This is the way you do it ... I want you to use this book, you can have your options ... he's refined it for 25 years, I think he's got it down pat ... and I thought, well, I couldn't do any better, so I just followed it. And we basically followed it to the letter.

Flume goes on to say that they do have some units that aren't from the book and she was able to do one unit of her own design.

Cathcart expects student teachers to be there everyday and to have a desire to work with children. He believes knowledge is not as important because one can usually find the knowledge needed. His view of his role as a supervising teacher is not to prevent the student teacher from making errors. When mistakes are made, they will sit down and discuss them. However, if it is a mistake that may hinder student learning, then it is his job to grab the wheel and take over.

I asked Cathcart if he had ever had a student teacher with whom he had some very different philosophies. His response was that he had, but it had never created a real problem.

> I'm so much older ... that when they come in, they're coming into my classroom and we've already set the stage with the students along certain patterns, particularly how to handle discipline and those kinds of things ... and they're willing to adapt to fit a particular situation. That doesn't mean they become little robots ... they're given a chance to try out different things ... but I think they realize that this is a classroom that is already established and the teacher in the classroom is the ultimate authority ...

When Flume was asked if she liked having a highly directive supervising teacher, her response was mixed.

> Yes I did. I don't know ... sometimes I'm good at taking orders and sometimes I'd rather do it all myself ...

The dialogues about discipline from Cathcart and Flume are remarkably similar. They both talk about how much kids have changed and how it is imperative that the teacher have good discipline. This is not a belief which Flume held prior to the student teaching experience.

> I also wanted to develop a sense of discipline, which Mr. Cathcart has excellent discipline. It's just boom, boom, boom, boom, boom. And dummy me, I started out being just a little lenient because I thought, goodness, he really rules these kids with an iron hand and they're scared to death of him. He's huge. He's a huge man ... that [being lenient] was the worst mistake I could ever do because I have fought that from day one now.

Cathcart quotes Flume as saying she saw teaching through "rose-colored glasses, I had no idea that discipline would be what it is."

Flume explained how Cathcart told her it was bad that she smiled when she disciplined students. She now realizes that Cathcart is right. She must learn to discipline without a smile. He has explained to her that she will understand the importance of this when she has children of her own.

I asked Flume if she saw Cathcart as being very authoritarian. She said that he definitely was. The kids are intimidated by his power, which is good because "they need someone to boss them around." Cathcart shows her articles in Education Digest that show you can't do anything until you get the kids quiet and you get the rules down.

Flume sees Cathcart as having a casual relationship with the students and she is somewhat jealous of that. However, she feels her rapport with the kids is good, too.

When Flume was asked what things she would do differently when she is fully responsible for a class, her only response was that she would use the overhead projector more and use more films.

In describing her expectations entering the student teaching experience, Flume said that she expected to be more confident. However, she stresses it is very important that she act confident in front of the class because of the fear that the students will take advantage of someone who is not confident.

Conclusions

Evidence from these interviews indicate that beliefs about science and science teaching strongly influence both classroom and laboratory instruction. These beliefs strongly influence laboratory instruction. Coverly, for example, teaches labs for the purpose of instructing the students on the importance of quantities because he believed that quantification differentiated science from non-science. Due to his view of science as a vast accumulated body of knowledge, he could not justify the use of discovery labs because they are too time-consuming and would reduce the body of knowledge he could teach.

Cathcart and Flume believe that science is discovered and use this as a rationale for discovery labs, which give the students an opportunity to be discoverers. (Even though the discovery was highly focused.) Cathcart holds strongly to the view that science progresses by very precise, accurate methods, i.e. the scientific method. For this reason he emphasizes using exact procedures in his classroom labs.

Nately believes that science is problem solving rather than facts or methods. He believes problem solving requires multiple points of view. This guides his instruction in solving problems. He encourages students having difficulty with a problem to attempt it from a different approach.

It is interesting to note that Coverly's remarks support the thesis that teachers' decisions about instruction are based on what they believe rather than on what researchers tell them. Coverly believes that chemistry should be taught as a combination of facts, process, and theory, even though he believes educators would tell him to teach chemistry as process.

From these cases, it can be seen that each teacher has a different system of beliefs about science and science teaching. In the case of Coverly and Nately, there were differences in their philosophies, but these differences caused no serious conflicts because neither attempted to impose their beliefs on the other. Although the curriculum was a significant constraint on the implementation of Nately's beliefs in classroom instruction, in many areas of instruction he was given a great deal of freedom.

For Cathcart and Flume, there were some differences in their beliefs concerning the role of the teacher. Flume was given little freedom to carry out instruction consistent with her beliefs because Cathcart was still in charge of the classroom. It is difficult to know if Flume's beliefs about science and science teaching actually changed because of her belief that "Cathcart knows best," or if she simply valued harmony more than her beliefs about science and science teaching.

Many of the beliefs discussed in the interviews had not been previously considered by the teacher. If their beliefs are not conscious, how can they be called beliefs and more importantly, how can they influence behavior? Sigel (1985, p. 362) states that people may not necessarily be aware of some of their own beliefs until questioned about them. In the analysis process they may draw upon a broader belief structure to answer the question. Subsequently, the new awareness may be incorporated into the existing belief system.

Implications for Teacher Education

Coursework required in typical secondary science certification plans includes courses in two content areas and in education. The courses in the content area rarely, if ever, address philosophical concerns in science. Furthermore,

education courses typically focus on "how-to" issues. There is little opportunity or encouragement during a teacher's formal training to develop a philosophy of science. As a result, teachers often are sent out with poorly developed beliefs about science (Wilker & Milbrath, 1972) because they have never been challenged. This is a tragedy. If a teacher's beliefs about science are indeed fundamentally important, then their teacher education should foster the development of a rich belief system.

Duschl (1983) found that the science teachers he studied held beliefs which were congruent with logical positivism. Examples of these beliefs include the usefulness of a step-wise scientific method, the objectivity of propositional knowledge, and the superiority of observational data over theoretical data.

The behavioral implications of belief systems have been examined by a number of researchers. Studies with math-anxious students indicate that these student tend to view mathematics as rigid, algorithmic processes that always give a precise answer (Buerke, 1982; Carter & Yackel, 1987). Mathematics is something handed down by an authority; not something to be carried out by ordinary people. Students are encouraged to overcome their math anxiety by changing their beliefs about math. If they believe that math is dynamic, intuitive, sensible, and usable, they are more likely to believe that they can succeed and will succeed.

Perry (1970) and Belenky, Clinchy, Goldberger & Tarule (1985) address the intellectual development of adults. In the early stages of development, people tend to view knowledge as right/

wrong, black/white, or good/bad - handed down to them by authority. As these individuals are exposed to multiple points of view, the rigid barriers begin breaking down. The faith in absolute authority and truth is in peril. The individual, in an effort to support opinion with evidence, becomes increasingly more aware that knowledge is constructed and contextual.

A liberal arts education should require students to examine their views of the nature of knowledge. In the case of science and math teachers, the nature of scientific and mathematical knowledge also needs to be probed. Buerke (1982) found that her students considered mathematical knowledge to be unquestionable "truth" even though they would not believe the same about other forms of knowledge. Carter (1987) found that many of her students held a view of scientific knowledge as absolute.

It is interesting that Coverly repeatedly made reference to his knowledge of the history of chemistry in answering the questions. Nately would probably be considered to have a very relativistic view of scientific knowledge. He had recently completed a course in the history of scientific technology. I would suggest that a thoughtfully instructed course in which teachers look at how science has developed, read what the philosophers have to say about science, and examine the present day scientific enterprise could stimulate the individual to create a more powerful belief system to guide them through classroom instruction. A number of others (Arons, 1980; Duschl, 1983; Hetherington, 1982; Klopfer & Cooley, 1963) have also suggested using history to illustrate the nature of science.

Directions for Further Research

Although the 45 minute interviews revealed some interesting relationships between teachers' beliefs about science and classroom instruction, it left more questions than answers. A more thorough study will be carried out this fall in which practicing teachers are interviewed and observed in their classrooms to learn more of this relationship. Perhaps it would be best to learn more about normal teaching practice before attempting to deal with the special constraints of the student teaching experience.

Also more work is needed in examining the implicit and explicit messages that students perceive from their teachers about the nature of science.

Understanding how beliefs about science are formed and how they can be changed are areas virtually untouched by research. If beliefs direct actions, the origins of these beliefs can provide us with powerful information to explain human action.

Appendix

1. Is science created or discovered?
2. What is the difference between scientific knowledge and other forms of knowledge?
3. Do you think science will change rapidly in the near future?
4. Several years ago the Psychology Department changed its name to the Department of Psychological Sciences. Can you venture a guess as to why they would do this?
5. At Purdue University, approximately 40% of the faculty in the biology department are female, less than 5% of the chemistry department are female, and 0% of the physics department are female. Can you offer an explanation for these data?
6. What do you believe are the most important theories of your discipline?
7. Why did you decide to teach? Why did you decide to teach science?
8. Do you believe that any of the issues we just discussed influence the way you teach?
9. Describe your practice teaching experience.
10. Do you believe you will continue to teach in a similar way as you have in your practice teaching experience?
11. Describe the ideal teaching situation. How has your practice teaching situation been different from ideal?

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DESIGNING EXPERIENCES TO TAKE ACCOUNT OF THE DEVELOPMENT OF CHILDREN'S IDEAS: AN EXAMPLE FROM THE TEACHING AND LEARNING OF ENERGY

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The curriculum development work of the Children's Learning in Science Project is based on a view that:

- learning is an active process in which existing conceptions are restructured and modified (by the learner) in response to new experiences
- children's prior knowledge interacts with taught ideas to influence their learning.

The teaching and learning described and discussed here took place during the development of a teaching scheme which was designed to address prior ideas about energy. In particular, this paper focusses on some of the learning issues arising during the course of the scheme, and on the barriers to conceptual change which emerged.

1 THE DESIGN OF LEARNING EXPERIENCES

The lessons on energy were developed by a 'working group' of ten teachers and two members of the project team, over a period of two years (1982-1984). A detailed description of the development process can be found in Driver and Oldham (1986), but briefly, the group's considerations were:

- a 'constructivist' perspective on the learning process
- information about children's prior ideas
- the aspects of the energy concept to which children could usefully be exposed during schooling.

1.1 A perspective on learning

A fundamental notion in current perspectives in cognitive psychology is that individuals construct their knowledge through physical and social interaction. It is also recognised that students' prior ideas are an important influence in this process.

This view of learning is the basis for the development of CLISP teaching materials, and is discussed in detail in Driver and Bell (1985). Some of the implications of this perspective are:

- through their direct experiences with the physical world, and through formal tuition, the child will have evolved a set of personal theories in order to explain events (see, for example, Pope and Gilbert 1985)
- both perception and the meanings constructed through generating links between perceptions and existing knowledge are influenced by what the learner already knows; the learner's investigation is directed by existing conceptions (see, for example, Osborne and Wittrock 1983; Posner et al 1982)
- conceptual change results from dissatisfaction with the capabilities of current conceptions, hence introducing 'cognitive dissonance', through 'discrepant events' may facilitate its occurrence (see, for example, Nussbaum and Novick 1982)
- the process of conceptual change is likely to consist of a number of steps, and although the teacher may affect the rate of change, by providing the 'right' experiences at the right times, ultimately control of learning lies with the learner.

1.2 Children's ideas about energy

Warren (1983) suggests that 'Energy is an abstraction used in the theoretical analysis of phenomena, and is not a commodity, a phenomenon or a sensation' and, further, that 'The only way in which one can have 'experience' of energy is by using the concept in an analysis or calculation'.

However, it seems clear that even if children cannot have direct experience of the restricted, physical science concept of energy, they do tend to describe some experiences using the word energy. (For an extended review of literature on children's ideas about energy, see for example, Brook, 1985.) For younger children, energy seems to be something which is associated with living things, or, more specifically, with human beings. Black and Solomon (1983) found that more than three quarters of their sample of 11 year old children associated energy with growing, fitness, exercise and food. Similar results were reported by Stead (1980) by Brook and Driver (1986), and by Watts (1983).

This anthropomorphic notion of energy might account for the strong association of energy with movement. Stead (1980) noted that for those children who said that energy was involved with inanimate objects, movement was given as the reason in many cases, and lack of movement specified as a reason for energy not being used. Brook and Driver (1984) also suggested that some children seemed to think that a non-moving object could not have energy.

Black and Solomon (1983) found that the proportion of children who associated energy only with living things decreased with age; many children began to expand their 'living' associations into a more general conceptualisation, which included non-living associations such as electricity, power stations, moving objects, lighting, sun, fire. However, by age thirteen, only about a third of the sample had a notion of energy as universal and quantifiable, in that it was seen as something which was possessed by all things and which can be measured.

As far as energy sources are concerned, children appear to recognise that humans and animals get their energy from food. However, children seem to have more difficulty in explaining what happens to the energy after the food is eaten. Relatively little work has been carried out in the area of ideas about energy conservation, but what there is (for example Black and Solomon, 1983) suggests that many students say that energy is 'lost' in transformations.

One interpretation offered by Duit (1981) for the results of his research, was that children do not see a need for the idea of energy conservation. Children aged between twelve and fourteen years were asked to predict heights and speeds for movement of a ball on frictionless tracks of various shapes. Although almost half of the students predicted accurately, none of the students mentioned energy conservation. In this study, and in giving written responses to a similar type of question in the work of Brook and Driver (1984), the explanations given by students who made correct predictions tended to focus on observable aspects of the phenomena, such as track geometry (height, steepness etc.) or in terms of 'force' or 'drive' rather than energy. Thus it appears that children do seem to use ideas which resemble aspects of the science notion of energy in predicting events, even though their understanding may be masked by their use of language.

1.3 A concept of energy

During the early months of the work of the group, decisions were made about an 'energy entitlement' forming three units of work across the 11-16 age range, which would address the following aspects of energy:

- energy transfer and transformation
- energy conservation
- energy degradation
- energy dissipation
- energy quantification.

Children's early associations for energy appear to arise from them operating in a context which is inappropriate for school science, but which is valid and valuable in their everyday world. They also appear to use intuitive, unspoken ideas about energy, identified as phenomenological primitives by diSessa (1983). These schemes, which are not mediated by language, are useful in making predictions about phenomena, but may be difficult for children to articulate using 'correct' terminology. One implication of a constructivist view of learning is that it is neither possible nor desirable to remove these ideas, replacing them with accepted science ideas. However, it was intended that the strategies and materials designed by the group may help children to build on their existing notions about the world, to clarify them, make them explicit, test and evaluate them. In this way children would extend their understanding of energy from its human-centred beginnings to a more general notion associated with the aspects listed above.

1.4 Energy experiences

In addition to outlining the concept of energy which would be approached in the schemes, the working group defined general areas of experience which could in themselves be valuable to future citizens. These included:

- energy requirement for physical activities
- food and diet
- domestic energy requirements
- energy sources in the home
- using energy efficiently
- world 'energy crisis'
- world distribution of fuel and food.

Lessons were built around these contexts, within which children were given opportunities to construct accepted ideas. In this way, each aspect of the energy concept is visited a number of times, in different contexts, so that even if some children are not successful in constructing accepted ideas, they may have had experiences (such as considering electrical requirements of different devices, reading gas meters etc.) which they can draw on usefully in their out-of-school lives.

A generalised constructivist sequence (Driver and Bell, 1986) was used as a guide for designing the lesson content. Each group of lessons begins with an 'elicitation' phase in which children share the ideas they have brought to the topic. Experiences which help children to modify and extend their ideas (restructuring) are then followed by application of new ideas and review of the change which has occurred.

The series of lessons designed for the younger age group (lower secondary school - 11/12 years) begins with experiences which are centred on human 'energeticness', moving on to discuss energy associated with movement in inanimate objects, and energy storage in foods, fuels and (later) in springs and raised objects.

Further lessons, designed for 13/15 year old students, begin with consideration of energy in domestic contexts and extend the 'fuel energy' notion from earlier lessons into a consideration of energy sources, uses and efficiency (in terms of cost) in the home. The group recommended that the 'entitlement' should also include opportunities for students to discuss issues concerned with energy distribution throughout world society; this area has not been developed to date.

Each of the units is self-contained and addresses all of the aspects of the energy concept outlined earlier. However, taken as a group, the units provide for continuity and progression of ideas across the secondary (11-16) age range.

2 THE CONTEXT OF THIS PAPER

The paper focusses on the first unit of work, an overview of which is shown in Figure 1, and is further restricted to six lessons within the unit, each of about one hour duration. The aim of these lessons is to explore 'what has energy?' (extending initial 'human-centred' views to a more universal concept of energy) and 'where does energy go?' (energy transfer, conservation, degradation and dissipation).

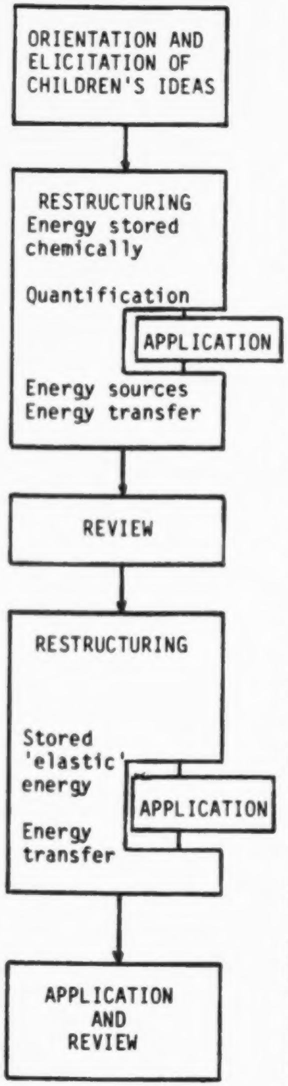
During the development of the teaching materials, the units of lessons were observed by a researcher member of the group, and audiotapes were made both of lessons and of discussions with children before, during and after lessons. Diagnostic tests, administered before and after teaching, provided additional information about the changes in children's ideas.

Two classes of children in two schools were involved in the study, and detailed observations made of small groups within the classes. School A is a boys' comprehensive (11-18) school in a small town, and class A was a second year (12/13) class described by the teacher as being in the middle ability range. School B is a mixed comprehensive (13-18) on the outskirts of a large city and class B was a third year (13/14) class described by the teacher as being of mixed ability.

3 THE SCHEME IN ACTION

3.1 Prior experiences: force

Both classes had review lessons on forces before the unit on energy began. Children identified forces in different phenomena involving themselves and inanimate objects, and



LESSON ONE
What do we already know about energy? Writing statements about energy, then categorising them: 'agree'/ disagree'/'not sure'.

LESSON TWO
Do we need energy to live and be active? Where does it come from? Do we get different amounts from different foods? How can we measure it.

LESSON THREE
How much energy do we need?

LESSON FOUR
Why is the sun's energy important? Tracing fuel and food energy to the sun.

LESSON FIVE
Review of ideas encountered so far. How else can we store energy (as well as food and fuel)?

LESSON SIX
Can inanimate objects have energy? Energy increases with height, force does not increase.

LESSON SEVEN
Measuring stored energy: marbles and sand tray experiment.

LESSON EIGHT
What happens to our energy when we are lifted? Where does energy go to when we fall?

LESSONS NINE AND TEN
Review of ideas encountered so far (including review of statements and categorisation). Design of 'machine' to store energy, then release it to do something useful. Consideration of degradation and friction.

Figure 1. Overview of ten lessons on energy, based on a generalised constructivist sequence (Driver and Bell, 1986)

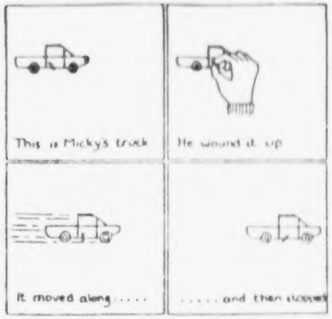
arrived at a broad definition of force as 'a push or a pull'. Class A went on to recognise that forces tend to 'try to speed things up or slow things down' but that there can be force without movement, and movement is possible without force. Class B discussed gravity and identified weight as a force.

3.2 Diagnostic pre-test

The diagnostic test comprised nine questions, each of which focussed on a particular aspect of energy. The pre-test results suggest that for both classes the primary association for energy (when asked for a spontaneous response to 'write a sentence including 'energy') was with human movement and fitness. A small number also seemed to associate it with food, fuel and electricity.

When asked whether energy was involved in specific phenomena - a moving toy car, a plant, a burning candle and a balloon, most of the children thought that energy was involved in each case, but only a few thought that the car, candle and balloon could themselves have energy. Most of the children focussed on human energy required to push the car, light the candle and inflate or burst the balloon.

The 'Micky's truck' question, shown below, addressed children's ideas about energy conservation.



Micky's truck had more energy after Micky wound it up than it had before he wound it up.

When the truck stopped, its energy was the same as it was before Micky wound it up.

What happened to the energy?

....

....

....

....

....

About half of Class A and two thirds of Class B said that the energy was used up, or ran out. In the case of Class A, a small number said that energy left the truck, but did not specify where it went. None of the responses explicitly mentioned transfer to the ground or to the air.

3.3 Energy and Ourselves: lessons one and two

The first lesson in the unit begins with children making their prior ideas explicit and sharing them with their peers. This took the form of children individually writing sentences about energy (five each) then sorting them, working in groups of four, into those which the group as a whole agreed with, disagreed with, or was unsure about. As expected, most of the sentences concerned energy needed by human beings to live, grow, exercise and be healthy, supporting the idea that the unit of work should use this as a starting point. An example of the categorisation from one group in Class A is shown below. The sentences which are marked * were given to each group by the teacher, to encourage discussion, and as a 'marker' of the change in ideas.

AGREE
We need energy to run around
Sun produces energy
Some energy is dangerous
Energy is important for life
* Plants get food energy from the soil, through their roots
Without the sun we would have no energy
Some types of energy are difficult to harness
Energy is important in modern day life
Athletes use plenty of energy each day
You need energy for electricity
The whole universe uses Energy
There are many different types of energy
Energy is important for light
Energy is important
Everything living needs energy

DISAGREE
* We need energy all the time, even when we are sleeping
* When a car runs out of petrol, it has used up its energy
* When we lift a weight, we give it energy

UNSURE
* Machines use up energy
* Pulling and pushing are examples of energy
* Solar panels use sunlight energy
* The world is running out of energy
* We sleep to get our energy back
Children have more energy than adults
Energy is an invisible substance

Lesson two focussed on using energy in physical activities (such as running on the spot, press-ups etc.). Working in small groups, children discussed energy transfers in their bodies. Whereas most children in both classes readily stated that energy comes 'from food, eating food', the process of transfer in the body and the question of what has happened to the energy after the activity has stopped seemed far from straightforward. Most children seemed to accept that the energy went somewhere, but where? For example (Class B, group discussion):

Janine	Where does the energy go?
Julie	In your arms.
Janine	Where does it go?
Samantha	It goes out.
Julie	Don't know where it goes. It goes out of your body to your arms. Don't know.
Lisa	Where does it go - it goes out of your breath.
Samantha	Out of your body.
Janine	Don't really know where it goes.

Class A also discussed the processes of transfer in the body (small group discussion):

Steven	It's like your muscles. Your muscles are there but they've just got to be pumped up. Same with your energy. It's there but it's got to get working.
James	I don't get where it comes out of, though.
Lee	It comes out of your legs.
James	Yeah, but how does it come out of your legs?
Lee	'Cos you use it.
Steven	Well, energy is in your blood, innit, 'cos if you do summat, you blood'll go faster, just like your heart. So therefore there must be energy in there, acting when you're running.

and later, when the teacher joined the group, some disagreement had evolved (Class A):

Steven	He says it comes out of your breath. You lose energy from your breath.
Teacher	Is that what you think?
Lee	Yes.
Teacher	And what have you said?
Steven	We said it comes out of your body. That it's still there but it can't be used for working.
Teacher	Mm, so you're not sure about that, are you, as a group.

During the whole class discussion which followed the group work, children were asked what happened to the energy for each activity (Class A):

Teacher	When you say it gets used up, what do you mean?
Lee	It goes.
Teacher	It goes where?
Lee	I don't know. We can't work it out.
Teacher	You can't work it out. O.K., fair enough. Can anyone help him out there? .... Brendan?
Brendan	The energy gets worn away.
Teacher	What do you mean by 'worn away'?
Brendan	As you're running up and down, it gets used up.
Teacher	So 'it's worn away' means it's destroyed?
Brendan	Yeah.

When other activities were discussed, children apparently picked up the word used by the teacher, and simply offered 'destroyed' as an explanation of what had happened to the energy.

In Class B, having established that the energy went somewhere (in class discussion following the activities), the teacher attempted to introduce the idea that the energy might be related to the increased temperature detected during the activities. The children did not raise any objections, but seemed to view this idea with indifference.

Lessons three to five dealt with sources of personal energy, and amounts of energy available from different foods. Both classes successfully established that energy is 'stored' in food, and went on to briefly consider storage in fuels. We rejoin the unit at lesson six.

3.4 Energy and objects: lesson six

Lesson six began with a demonstration in which one child held an object at the front of the class and discussed what was happening in energy terms. Two main issues arose:

Relationship between weight and height

Teacher A reminded his class that weight does not increase with height, and the children seemed to agree readily (a forcemeter was available and this was checked). However, some still suggested that the action of gravity might be different at different heights (Class A):

Ahmed	Sir, you've got to use more energy because there's more gravity pulling it down now because it's higher up.

In Class B, although all of the children said that more energy was needed to lift the object higher, there was some disagreement about whether the weight increased. In discussion with the researcher after the lesson, two boys explained their reasoning:

Researcher	So why is it - why does it hurt more when you hold them higher up?
George	Gravity's pulling them down even further and

it's your arm that's straining to pull it up.
Researcher What do you mean by 'even further'? ... What do you think?
Paul When you higher it up it hurts more.
Researcher Yes, but why?
George Because of gravity.
Researcher What do *you* think, Paul?
Paul The same (as George).

With further probing, it emerged that George had thought through the problem and arrived at the 'theory' that weight increased if the object was being lifted by a person, but otherwise stayed constant. Thus different types of weighing devices produced very different results (Class B):

Researcher What do you think you're measuring? When you measure on this spring balance thing?
George Gravity.
Researcher Do you think that's different from a weighing scale, like a bathroom scale?
George Yes, 'cos the bathroom scale's on the floor. It's just pulling down, you're not holding it.

Can an object have energy?

Although they readily admitted that energy was used by the person lifting the object, Class A denied that the object itself could have energy at any time, even when pushed by the teacher:

Teacher Why should the weight fall then?
Matthew Because gravity pulls it down.
Teacher Gravity pulls it down ... you need energy to push up, but not to fall down?
Matthew You do. You need energy for lifting, but when you let it go it's only gravity pulling it down.

The class then went on to discuss force and energy in a number of practical activities, working in small groups. The devices included a wall mounted manometer, syringe connected to balloon, vibrating rule. During group discussion, all of the groups agreed that energy was involved for all of the devices, but only considered their own energy, for example in the case of the syringe and balloon, 'it's involved from me - er - from my arm - from my hand'.

When the groups in Class A reported on their ideas and findings at the end of the practical activities, most denied that energy was involved other than in their bodies. For example (vibrating rule):

Teacher Where's the energy? I'll just hold that down.
Andrew In your finger.
Teacher In my finger. Is there any energy in that rule at all?
Andrew No, Sir.
Teacher When I let it go, will that rule vibrate?
Andrew Yes, Sir, it'll start to vibrate.
Teacher ... will it need energy to vibrate?
Andrew No, Sir.

However, there did seem to be some change in ideas as the reporting progressed and children were asked to consider what had happened to their energy. In discussing the manometer (Class A):

Teacher ... Is there any energy there now or has the energy from my body gone?
Lee It's gone out of your body.
Teacher The energy that I used to push the liquid up to that level, what's happened to that energy?
Brendan It's been used up.

Teacher	... So there's no energy left in there?
Brendan	Yes.
Teacher	If you say yes, where is it?
Brendan	In the pipe.

Towards the end of the lesson, the discussion again turned to the raised object - a brick - which was now tied up near the ceiling of the laboratory. At this stage, the distinction between moving and stationary objects became clear (Class A):

Mark	Sir, it can't be getting energy, because it's not a living object.
Teacher	So are you saying that only living objects have energy?
Matthew	No, Sir - electricity.
Andrew	Cars have energy.
Teacher	Yes, he's got a point. A car has energy. Well, if a car can have energy. Why can't a brick have energy?
Andrew	A car's moving though - gets energy from petrol.
Teacher	But you're going to tell me that that brick has got no energy.
Steven	Ah, but it's gravity what's coming down on it.
Teacher	I'm asking about energy - not force. Does that brick (points) have energy?
Steven	No.
Teacher	If I take that brick and I hold it high up and then I drop it, has it got energy?
Steven	Yes, it's moving.

At the end of the lesson the teacher took a vote on who thought the brick had energy when raised and stationary. More than three-quarters of the class said that it had not.

Class B, like Class A, willingly accepted that energy was used by the person lifting the object, but they seemed doubtful about whether the object itself could have energy.

The class was then invited to discuss the energy involved in raising one of their number on a pulley system. The class drew a clear distinction between living and non-living objects (Class B):

Colin	Well, you've got to have energy to live haven't you. You've got to have energy to breathe.
Peter	There'll be energy to hold onto t'rope.
Colin	Yeah, he'll be using energy.
Teacher	Imagine that Paul were dead. Would Paul -
Colin	No, he wouldn't have energy.

3.5 Energy and objects: lesson seven

Between lessons six and seven, both teachers gave a great deal of thought to how best to convince their respective classes that inanimate objects could store energy when raised. Both teachers chose to return to the demonstrations of the previous lesson to review children's ideas. Teacher A dropped his large brick, causing spectacular damage to a cardboard box, and when Class A was asked to vote again about whether the raised brick had energy, most of them said it had. However, they seemed unsure, and unconcerned, about why they had changed their minds (Class A):

Researcher	... What made you change your minds?
Steven	I don't know, really. I think most of us realised that energy was involved.
Researcher	Can either of you remember what happened to make you change your mind?
Steven	Oh, yes, lifting that weight up and then dropping it.

Teacher B began by reminding the class that they had all agreed that the object had energy when moving, and asking where this energy could have come from. The class seemed to have accepted the idea, which was then reinforced during the lesson, when children investigated the effects of dropping marbles and ball bearings (same size, different mass) into sand trays, from different heights (Class B, small group discussion):

Wayne	Marble's got more energy at 100cm, you know.
Terry	I *know* but it doesn't weigh more, 'cos we've just done it.
Wayne	It doesn't weigh more, but it's got more *energy*!

and another group (Class B):

Janine	How can you tell that a heavy object has more energy?
Julie	'Cos a heavy object - 'cos you need more energy to push it up, right, so it's storing more energy - your energy. It's storing more.

In discussion with two groups of children after the lesson, the ambiguous attitude to weight and height in Class B was clarified (discussing dropping object of same mass from different heights):

Researcher	... You still think the weight would be the same?
Together	Yeah.
Julie	Not when it landed.
Researcher	It won't be the same when it's landing?
Lisa	You mean when it makes noises. It makes a noise when it's landed.
Julie	Yeah, 'cos, say for one's like that and one's like that (holds similar objects at different heights) and they both drop, that's going to be heavier than that one. That's had much further to travel.
Researcher	When will it be heavier?
Julie	When it gets to the sand.
Researcher	When it actually hits the sand?
Together	Yeah.

Another group in Class B, interviewed after lesson seven, appeared to have intuitive, though not well-articulated, ideas about *how* energy was related to mass and height. In this transcript extract, George has predicted that, for a marble to make the same dent in the sand as a ball bearing of twice its mass dropped from 50cm, it would need to be dropped from 100cm:

Researcher	About 100. Why do you think that?
George	Because it's lighter, so it'll have to travel from a higher space.
Researcher	But why do you say exactly double?
George	If they were the same weight, then you could drop 'em about 50, but they're not, so you'd have to drop one from about a hundred.
Researcher	But why a hundred?
George	'Cos it's - erm - two times the amount of what the other one is ... 'Cos when - if it's heavier than the ball - than the marble, then when you drop a marble, it'll make a big dent, but when you drop a ball bearing from same height, it goes harder down, so that's why you have to increase height, to make it the same.

Lesson eight extended ideas developed in lessons six and seven to consider energy changes for humans lifting themselves and being lifted. We rejoin the unit at lesson nine.

3.6 Energy conservation: lesson nine

Teacher A had continued to ask his class 'what happens to the energy?' whenever appropriate, which seemed to have dispelled the notion that it was 'destroyed' for some children (Class A, small group interviewed after lesson seven):

Researcher What do you think happens to it (the energy) when you drop something?
James Energy's used up.
Researcher It's used up. But you said it can be passed on. Is it passed on anywhere, or does it just disappear?
Lee Just disappears.
Researcher Do you all think that? Because you weren't sure about that, were you?
Steven It might be passed on into the sand when you -
James Yes.
Steven (to James) What do you think?
James I think it'd be passed on into the sand.

However, at the end of lesson seven, both classes were unsure about what happened to the energy when it seemed to disappear (Class A discussion at the end of lesson seven):

Teacher When that falls, what will happen to the energy when it hits the sand?
Steven It'll spread out in the sand.
Teacher You think it'll spread out in the sand somehow. It's transferred to the sand. Does anybody agree? (No response.) Does anybody partly agree that energy might be transferred into the sand? (About half of the class raise hands.) Who totally disagrees? Who still says that energy must be destroyed?(About a quarter of the class raise hands.) So we're not quite sure on that.

During lesson nine, about half of Class A continued to maintain that the energy would be destroyed. This lesson was designed as an opportunity for children to apply the ideas they had learned about stored energy to help them to design and build an 'energy storage device'. In the case of Class A, design was restricted by the teacher, who asked all of his class to work in groups to design a 'toy tank' using cotton reels and elastic bands. Most of the class agreed that energy was stored in the elastic (group discussion with teacher, Class A):

Teacher What's happening to the energy as I wind that tank up?
Steven It's being passed on by you to that -
Mark Elastic band and it's storing it.
Teacher So if I stop now (stops winding), where's the energy?
Steven In that elastic band.

Towards the end of the lesson, the teacher led a report back from the groups about the energy changes in the tank, and the uncertainty about what happened to the energy became clear as a number of suggestions were made. For example:

Lee Sir, could it be that when you wind it up you give the energy and then when it stops and you pick it up it gives the energy back to you?

After long discussion, the teacher pointed out an apparent inconsistency in the children's reasoning:

Teacher If I get my energy from food, if I use that energy to wind up the toy, if that energy is stored in the toy and then the energy is needed to move the toy along, and the energy eventually goes, why suddenly should the energy be destroyed? Why shouldn't it be destroyed before?

However, the problem was not apparant to the class; and the teacher needed to make his view more explicit:

Steven	Sir, because there's a certain amount of energy in it, Sir, and it takes quite a while to use that energy up.
Teacher	Why is it destroyed, and why isn't it just passed on?
Steven	Sir, because there's nowhere to pass it.
Teacher	Isn't there? These (other children) said it could be passed on to the bench or into the air.
Lee	How's it going to get there, Sir?
Teacher	How does my energy get from my arm to the toy to start with?
Lee	It's passed through your fingers.
Teacher	Well, couldn't it be passed through the wheels?

A long and tortuous discussion followed in which the teacher used the analogy of his own motor car in an attempt to introduce the idea that heat is evolved in transfer of energy. Like Class B (lesson two), Class A offered little response to this idea (Class A discussion):

Teacher	If you went to the tyres (when the car had been moving for a while) would you feel something?
Lee	Yes, they'd be warm.
Teacher	... Something's happening. Is heat somehow connected with energy?
Class	Yes (about five children responding).
Teacher	So there's a possiblity that there's a change of energy between the car and the road?
Class	Yes (three children responding).

Teacher B chose to allow the children to engage in a more open-ended design activity, which proved to be less successful than the more restricted work of Class A. Discussion focussed on improving the design of the devices (spring-catapult, bow and arrow) rather than on energy considerations.

3.7 Review of ideas, and diagnostic post-test

At the end of the unit of lessons, children were asked to review and revise the categorisation of statements produced in lesson one. There was a little movement of the statements written by the children themselves, but a larger difference in the categorisation of those given out by the teacher. Most of the groups maintained the statement 'when we lift a weight, we give it energy' in the 'unsure' or 'disagree' category, although there did seem to be a drift of sentences about 'non-living' things towards the 'agree' category. The changed categorisation for the group used to provide the earlier illustration is shown below:

AGREE
* Machines use up energy
Some energy is dangerous
We need energy to run around
Sun produces energy
Energy is important for life
* When a car runs out of petrol it has used up its energy
* Plants get food energy from the soil, through their roots
* Without the sun we would have no energy
Some types of energy are difficult to harness
Energy is important in modern day life
Athletes use plenty of energy each day
You need energy for electricity
The whole universe uses energy
There are many different types of energy
Energy is important for light

Energy is important
Everything living needs energy
* Solar panels use sunlight energy
* The world is running out of energy
* We sleep to get our energy back

DISAGREE
* Pulling and pushing are examples of energy
* We need energy all the time, even when we are sleeping
Children have more energy than adults
* Energy is an invisible substance

UNSURE
* When we lift a weight we give it energy

The diagnostic post-test results suggested a more marked change in children's ideas.

When asked for spontaneous ideas about energy, there was a slight increase in students who mentioned the sun, food or forms of energy (heat, light). This change was more pronounced for Class B where less than half of the sentences written concerned human energy, and more children mentioned the sun, food and energy as 'needed to make things work'. When asked about energy in specific phenomena, both classes had an increased tendency to mention sunlight energy in the case of the plant, and heat and light energy for the candle example. Some children in Class A also mentioned sound and movement energy for the balloon. for both classes, there was a slight increase in the numbers of children who said that energy was involved for the toy car, but 'human energy' still dominated the responses.

For the question about energy transfer in 'Micky's truck', about a third of the children in Class A said that energy was used up or ran out, but there was some movement of children who gave responses like this in the pre-test towards responses such as 'energy was passed to the ground'.

For Class B, about two thirds said that energy was used up, but again, there appeared to be movement; about a quarter said that energy 'left the truck' or was passed to the ground or air.

4 SUMMARY AND DISCUSSION

Children's ideas did appear to develop as the unit of lessons progressed. Their initial notion of energy, associating it primarily with human beings, and ultimately suggesting that it is 'used up' in movement, moved towards a more general view of energy - stored in objects like springs, elastics and raised weights, and conserved when it is transferred. However, the route which children took in changing their conceptions was not straightforward, and issues arise in two main areas:

4.1 Conceptual problems

A number of conceptual barriers appeared to be common to both classes:

Variation of weight with height

Both classes reasoned that weight would increase as an object was raised. This was refuted early on by teacher A, but the idea that gravity was 'pulling down more' continued to be used as an explanation for the different effects when objects were dropped from increased heights. Thus energy explanations were superfluous; the children could adequately account for their experiences without accepting that the object's energy must have increased as it was raised. Only after it was established that gravity did not change as the weight was raised, and the inconsistencies in children's reasoning were emphasised by the teacher, did they begin to think that the object could itself have energy.

Stored energy in objects

Both of the classes strenuously denied that non-living objects could have energy at the beginning of lesson six, but by the end of the lesson, through linking energy in falling objects with other moving objects where energy seemed more obviously involved (cars and buses for example), Class A appeared to accept that the object could have energy as it fell to the ground. Class B had also already established that fuel was a source of energy; it may be that if a parallel had been drawn between a moving weight and a moving car at this stage, the class would have taken a similar step forward.

The notion of energy conservation might have helped students then to go on to construct the idea that the stationary weight must have energy. However, children had only partially made sense of the 'where does the energy go?' question, and it was not until the beginning of lesson seven that children were prepared to accept that the object could have energy although neither living nor moving. It is not clear what caused the children to change their minds (the children themselves were not sure what had influenced them), although it seemed that the damage done when the objects were dropped made the idea that energy was stored then released more credible.

Energy conservation

The idea that energy is not destroyed, but can be transferred is implicit in the unit of lessons, since the question 'where does it go?' was asked throughout. Class B seemed prepared to accept that the energy goes 'somewhere' although they could offer no explanation of where it went, as early as lesson two.

Class A appeared to grasp the notion that energy was 'destroyed' suggested by the teacher as a word for one student to use, and this hindered their construction of energy being 'passed on' until the end of lesson seven. Once constructed, this idea seemed to be reinforced when they built and tested toy tanks in lesson nine. The fact that this application phase was less successful for Class B may account for the difference in the diagnostic test results for 'Micky's truck' for the two classes.

4.2 General learning issues

Driver and Bell (1986) suggest a number of implications of constructivism for the design of teaching and learning materials. One of these is that children need to be given opportunities to reflect on their existing ideas and construct meanings from their classroom experiences. This study suggests that, viewed from this perspective, the process of conceptual change in science places particular demands on both children and teacher.

Children realise early in the unit of work that a number of viewpoints can exist about a particular phenomena, and that they may all be valid and worth of analysis, including the teacher's 'science' perspective. Throughout the schemes, children are expected to take responsibility for their own learning, to be prepared to review and change their ideas in the light of new experiences or discussion. This may involve them exposing firmly held beliefs to criticism from their peers, which may be threatening initially, but the two classes seemed to overcome their nervousness quickly and appreciated the opportunity to share their thoughts:

Colin You get to see - well, hear - what everybody else thinks and that makes it a lot more interesting than just sitting down and writing loads of pages out.

The teachers also needed to be prepared to accept different viewpoints - those of the children, and to allow the class to explore their ideas before they introduced their own, so as not to 'short circuit' children's thinking. The effect of introducing the teacher's viewpoint too early was demonstrated by the prevalence of the idea that energy was 'destroyed' in Class A during lessons two to five.

Perhaps a more difficult aspect of the teacher's role is that of diagnostician. Both teachers were aware of the conceptual path that their classes were taking, and adapted the lessons accordingly. At critical points in their teaching, the problem of deciding which strategy would be most appropriate faced each teacher, as one remarked in his diary of the lessons:

> 'Pleasantly surprised by how smoothly it went. However, teacher is required to plan carefully and be able to 'think on his/her feet'. The course as a whole seemed to be enjoyed by pupils with good group participation.'

Finally, each of the teachers needed to accept that children may not change their ideas quickly, and that the process of change may not end with the end of the energy unit:

> "I think some of them are going to come out and they're going to still give the same answers to the questions on the tests but I think some of them will have learned something and I hope all of them have a basis for looking at things again, and prodding again and again and again and eventually they'll come up with an understanding. But I don't think I'm going to do it in ten lessons.'

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HOW CHILDREN KNOW BIOLOGICAL STRUCTURE-FUNCTION RELATIONSHIPS

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Science education in the elementary school is our main concern. The general objectives of our research originate from a constructivist view of pedagogy, which has an ancient tradition in our country but which has received new support by the recent advancement of studies on cognitive processes. Our general objectives are to investigate conceptualization related to the biological domain, which is an area that has received less attention in investigations on naive conceptions, though not less engaging and with interesting specific aspects which may shed light on the use of natural logic and its connections with the object it is applied to.

Our work aims at describing how conceptions are mentally organized and mobilized rather than what is their content, how they are related to the contextual situation in which they are used and the communicating medium they are expressed through.

The outcomes we expect from these studies are indications for developing teaching methods, for improving interactive strategies in the educational setting, student-teacher and peer-interactions, in order to make effective the sharing and the production of meaning. We envisage a change in the strategies which characterize the initial formation of teachers to make their training consistent with the educational objectives and the school practice that official documents and law apparently promote in our country.

This report will account for one part of our investigation which was focused on a relational concept, a critical one in the interpretation of the living world:the structure-function relationship.

Our leading questions were:

- do pupils use this relationship to explain the functioning of living beings?
- how do they manage this concept at different ages and school levels, assumimg that school instruction and mass media give relevant informational inputs on biological phenomena?

The reasons why we selected this problem descend from our theoretical assumptions and general objectives:It is a concept that has to be built up, possibly at the intersection of different inputs, such as personal experience, school education information.Therefore,if constructed it is a mental model and not just a memorization.

In this same line decisions were taken about the methodological design.They were the following:

- to start probing a broader sample of students representative of three school levels of the schools in Rome, then to go deeper into a restricted sample (one school class for each level), so that more detailed analyses could be carried out on a larger number of records;
- to compare three age levels, because this method allows the most meaningful features of the mental representations and their dynamics to be emphasized;
- to meet pupils by inviting the school classes in our lab for two consecutive mornings and to develop with them a standardized but motivating sequence of activities;
- to insert in the sequence, at selected steps, activities which may cause changes in perspectives, recall of events, focus attention on facts;
- to collect data engaging pupils in tasks which might elicit their mental representations through different cues, and were demading the use of different communicating media;
- to gather either individual either collective products by involving pupils in group-works;
- to stimulate group discussion through a pre-fixed grid of questions;
- to appeal to fantasy, by asking children to immagine solutions that, although unreal, are bound to pre-defined rules.

In the Appendix we summarized the work-schedule, the types of tasks and their presentation, the records gathered when the school classes came to our lab and children were invited to reason on the relationship between human skeletal structure and movement.

We treated record essentially with qualitative analyses carried out by two people who had trained together and reached a checked agreement.

Individual performances were evaluated or classified into categories either by criteria of adequacy to the scientific knowledge in the subject matter, either by criteria suggested by the products themselves in that they were revealing of cognitive differences across the whole sample.Transcripts from audiotapes were a source of information for tracing back the individual contributions to the group-work and for reconstructing the work procedure followed,the negotiations which accompanied it.Furthermore, propositions produced in response to adult questioning were isolated .

We will not discuss here all the results obtained from these transformations of our data, the interconnections among the performances , the male-female comparisons and so on.We will synthetize some of our conclusions.

Our first remark is that the percentage of pupils able to graphically represent the human skeleton though clearly changes along the school career doesn't reach the value which might be expected, considering that human body is a topic included in the curriculum of compulsory school. See TABLE 1.

We must point out that we tried to keep separate the drawing from the cognitive ability when we evaluated the pupils' performances.The work-sheets in Fig.1 were both included in the category of "essentially functional skeletons" because they displayed the main critical features; these features were part of the items which formed a grid used to assess the degree of correspondence of the drawings with the scientific representation of the skeletal structure.

Our second remark is that pupils , even though not reproducing this idea, use graphic symbols to convey their ideas,since typologies can be recognized in their drawings.We found five categories;

A)- "outer frame-type" (Fig.2)

B)- "stuffed in-type" (net-like signs or sparse Pluto bones are most frequently found). (Fig.3)

C)- "semi organized pieces or bones-type" (Fig.4)

D)- "iron wire core-type" (Fig.5)

E)- "organized pieces or bones-type" (Fig.6)

There is a clear tendency of evolution from type A) to type E) along schooling (see values in TABLE 2); but since all the five types were found at any of the school levels considered in the sample, they seem to indicate the evolutive changes of a conception rather than being correlated with developmental stages of cognitive structures.

We presumed that the different categories could be matched with statements concerning the structure-function relationship, that we formulated as follows:

"Skeleton is something which is everywhere in the body to keep its shape"

"Skeleton is made of pieces, mainly in the legs and in the arms, and pieces are not at random"

"Skeleton is the supportive hard core of the body"

"The pieces of the skeleton have a definite organization, are interconnected to support and to make the body moving".

The propositional content of these statements is obviously different.To test the validity of our interpretation we planned the second deeper probing on a restricted sample of school classes.Furthermore we suspected that we might have induced the "fill-in", more naive, responses submitting to the children work-sheets which had the body outline already drawn.

The performance of the youngest pupils remained more or less the same when we asked them to sketch the skeleton on a white work-sheet (Fig.7); this was not the case with the other two groups of pupils:the great majority of their drawings entered in type E) category.The new presentation of the task, then, pushed them to concentrate on the skeleton as something which needs to be structured and self-supportive when "the container" is lacking.

Another interesting observation was done concerning the effect that inputs, such as perceptive experiences, exchanges among peers, the dissection of the rabbit's leg, had on students' achievements. They didn't significatively modify the products of the youngest pupils; they seemed to produce a certain degree of disorientations in the 4th grade pupils, whose repeated work-sheets were worse than the previous ones and answers in the problem-solving task spread over a wider range of solutions rather than concentrating; they promoted improvement in the achievements of the middle school students (See TABLE 3, comparing the values in columns 1 and 2)

By matching the informations coming from the analysis of drawings with those comimg from the skeleton's models assembled by pupils working as teams, we reached the conclusion that the majority of the 2nd grade pupils are unable to differentiate the skeleton's representation from that of the whole body.Children look troubled by this request and seem to use their own stereotype of "little fellow" as a safe basis for their performances.

Usually, the building up of the model (See the Appendix for details on the presentation of the task and its order in the overall sequence)started with a claim like:"I will make the head" and with negotiations about the sharing of the parts of the body; children worked in parallel, without coordinating among them, unless the adult solicited them to compare their end-products' dimensions or to avoid the doubling of the parts, or to match the left with the right side.The use of plasticine rather than of straws, the comments exchanged during the manipulation ("I will do the face","Look,he lacks the ears", "I am making the body"), all is revealing children's difficulty to analyze the inner as separate from the outer perceptible shape. The adult who assisted the team at work repeatedly reminded that the model had to be intended for showing other teams what they knew about the skeleton, but this stimulation didn't generate more interaction focused on the cognitive aspects of the task.

The static rather than the dynamic function of the skeleton is stressed by the youngest pupils, as far as drawings and models are taken into account.

However, when the answers produced during the group discussion are examined it appears that they are aware that skeleton is needed to move oneself.

"What is the skeleton for?" :

> "So that we can move"
> "To move my arm"
> "To play foot-ball"
> "We would not be able to do anything"
> "We would not even had the meat over because it could not stick to anything"

Movement is explained by 2nd grade pupils in terms of a necessary consequence of being alive or;"Is you that move the bones" "The brain orders me to move" .Blood, skin, food are considered factors; meat is mentioned sometimes, but never muscles are.

"What are muscles?":

> "Those you have here (indicating the forearm) "
> "The toughball that bulges when you close your hand tight"
> "They are needed for boxing"

In conclusion, the functioning of oneself better than of the body is perceived and considered; it is accepted as a matter of fact which doesn't require further explanation:many necessary parts are within the body and they function because the body is living.

The nature of the relationship between skeletal structure and movement gets clearer to the students of the other school levels considered.

In a higher percentage of their drawings the joints between the skeletal pieces are marked; arms and legs do not articulate directly with the spinal cord .The pelvis appears in most of the 4th grade pupils'representations,while shoulders are frequently represented only by middle school students (See TABLE 3).The joints in the legs appear earlier than the joints in the arms.

The performances in the task of modeling confirm these data. Straws are used instead of plastcine to figure the bones. Even the procedures get different.Middle school students start by making up the spinal cord and go on by adding the other parts to this, as soon as they accomplish them; they are very concerned about proportions, they make appraisals and often express dissatisfaction with the end-product.

Whilst the 4th grade pupils relate the movement to the presence of the nerves and veins, but in so far as they give "force" "strenght", "energy", the older pupils appear to have acquired a model of the functioning in which brain, nerves, muscles and bones play integrated roles in causing movement.

At least when they discuss with the adult within the group. However, when they are requested to add the muscles to the arm or to the leg's bones drawn on the work-sheet (Fig. 8 - See the Appendix for details about the tasks's presentation), they do not perform much better than the younger pupils. Only the 20% of them draws the muscles linked with two different bones jointed together.

Thus we claim that the performances at the representational level result poorer than those at the verbal level, particularly when the conceptions are still "fuzzy" ones.

Middle school students solve the problem of applying a rubber band between two nails inserted in two different pieces of a wooden model of a leg (See the Appendix) better than the 4th grade pupils:65% of correct solutions versus 25% given by the younger students.

They seem, therefore, to have reached an awareness of the fact that traction is exerted between a fixed and a movable point when this one has to be lifted. Nonetheless they do not use this type of knowledge when they are requested to relate muscles and bones.

From all the observations we made and the remarks that we have pointed out, it seems to us that a meaningful issue has to be underlined because it is relevant to the development of teaching methods.

Mental representations appear to be multidimensional, flexible structures which are enacted accordingly to the requests and which are shaped by the features of the situation.

Coherently with this claim schooling should:

- promote teacher's and student's awareness of these models and of the processes underlying them through the practice of different media for representing them in a context where negotiations among individual representations is needed;
- challenge the consistency of these models confronting the pupils with tasks differing in cognitive demands and eliciting different levels of mental encoding : propositional, perceptual, emotional, procedural.

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APPENDIX

SKELETAL STRUCTURE AND MOVEMENT

TASK SEQUENCE WITH THE BROADER SAMPLE (SS=238)

1)- "Observe these animals and yourselves while moving.Touch the bodies and focus your attention on different types of movements, in order to figure out what the inner skeletal structure should be like to function as it does" .
Group setting. Time 3o'.

2)- "Sketch the skeletal structure within the outlines drawn in this work-sheet".
Individual task. Time 30'.

TASK SEQUENCE WITH THE RESTRICTED SAMPLE (SS=56)

First morning

1)- "Sketch the human skeleton according to your own idea ofit"
Individual task on a white work-sheet. Time 20'.

2)- "Let us confront the drawings".
Few minutes of verbal interaction within the group (4-5 pupils each group).

3)- "Why not to concentrate on our own body;touching its parts we have the possibility of perceiving how some bones are structured, of experiencing movements and constraints to some of them,etc. We can tell each other what we discover and make descriptions of what we feel".
Group setting.Audiotaped. Time 20'.

4)- Group discussion based on a grid of questions;
- do males and females differ in their skeletons?
- has a newborn a skeleton? Does the skeleton of a baby differ from that of an adult? Are bones alive? Do they grow and how?
- does the skeleton of a fat man differ from that of a tin man?
- what is the skeleton for?
- how does it function?
- why can't a narcotized man stand even though he has bones, conceded that someone holds him up?

Audiotaped. Time 30';

5)- "Repeat now the sketch of the human skeleton and write what you change, if you change something in this second drawing".
Individual task. Time 15'.

INTERVAL (20')

6)- "Add the muscles to the arm bones drawn in this work-sheet, the ones acting when lifting objects".
Individual task. Time 15'.

7)- A problem-solving task in a group setting:"Cause the wooden leg to move", Individual predictions are requested then tested at the end of a turn, eventually repeated if none of them provide a solution.The questions were:
"Where would you place the rubber ring in order to have this wooden leg positioned like this (lifted and bent)?"
"Now,having it returning straight but leaving the first rubber ring in place?".

8)- "Add the muscles to the leg's bones drawn in this work-sheet, the ones acting when lifting the leg".
Individual task. Time 15'.

Second morning.

1)- Dissection of a rabbit's hind leg performed by an adult.
Group setting.Time 1 hour.

2)- The same task as in point 6).

INTERVAL (20').

3)- "Build a human skeleton by using these materials:straws and plasticine".A wooden board with an iron wire driven into it was supplied as a support.
Group setting.Collective task.Audiotaped.Time 1 hour.

About one month afterwards we went to school and asked pupils to invent a story dealing with a strange land where people had not the skeleton.

TABLE 1

ASSESSMENT OF FUNCTIONALITY IN SKELETON'S DRAWING OF THE BROADER SAMPLE (SS=238)

	ELEMENTARY		MIDDLE
	2 S=64	4 S=88	2 S=86
joints in the arms (elbovs and wristles)	11,0 %	22,8 %	64,0 %
joints in the legs (knees and ankles)	6,3 %	36,4 %	61,7 %
arms articulated with shoulders	12,5 %	21,6 %	53,5 %
legs articulated with pelvis	4,7 %	30,7 %	65,2 %
essentially functional skeleton	1,5 %	9,1 %	32,5 %

TABLE 2

DISTRIBUTION OF DRAWINGS OF THE BROADER SAMPLE (S=238) AMONG THE FIVE IDENTIFIED CATEGORIES

	ELEMENTARY		MIDDLE
	2 S=64	4 S=88	2 S=86
TYPE A "frame type"	18,8 %	4,6 %	5,9 %
TYPE B "stuffed in type"	32,9 %	16,0 %	4,7 %
TYPE C "semi-organized pieces type"	20,4 %	17,1 %	4,7 %
TYPE D "iron wire core type"	20,4 %	22,8 %	12,8 %
TYPE E "organized pieces or bones type"	6,3 %	39,8 %	71,1 %

TABLE 3

EVOLUTION IN FUNCTIONALITY OF THE SKELETONS DRAWN BY THE STUDENTS OF THE RESTRICTED SAMPLE
(one school class for each grade)

	EL SCHOOL		MID SCHOOL	
	4th grade		2nd grade	
	Work-sheet 1	Work-sheet 2*	Work-sheet 1	Work-sheet 2
joints in the arms (elbows and wristles)	43,7 %	31,2 %	40,0 %	50,0 %
joints in the legs (knees and ankles)	62,5 %	37,5 %	55,0 %	90,0 %
arms articulated with shoulders	18,7 %	12,5 %	40,0 %	75,0 %
legs articulated with pelvis	87,5 %	93,7 %	60,0 %	100 %

EXPLANATIONS TO THE TABLES

TABLE 1- The sample consisted of four classes for each of the school levels considered.Pupils were 7,9,12 year old. Increasing percentages of drawings reproduce functional elements of the skeletal structure as schooling progresses. The drawings included in the last category display all the above-listed features.Only 32.5% of middle school students produce drawings in this category.

TABLE 2- The Table illustrates the change in distribution of the drawings among the five categories, and shows how all of them persist along the school career.

TABLE 3- The restricted sample consisted of one class for each school level;only two of them are taken into account in the Table.Data in columns 2 deal with the sketches repeated by the pupils after having experienced their movement and after the discussion about the skeleton's function.

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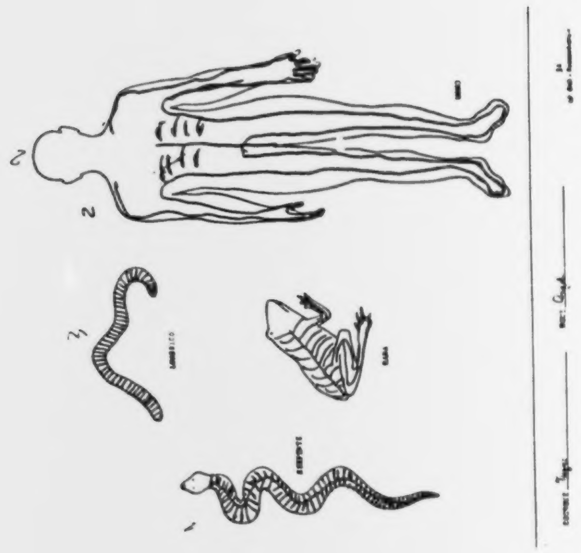

FIG.2 - In this and in the following four Figs. work-sheets of 4th grade pupils are reproduced.Our comments in the text deal with the human skeleton only.This drawing is representative of type A,the "outer frame-type".

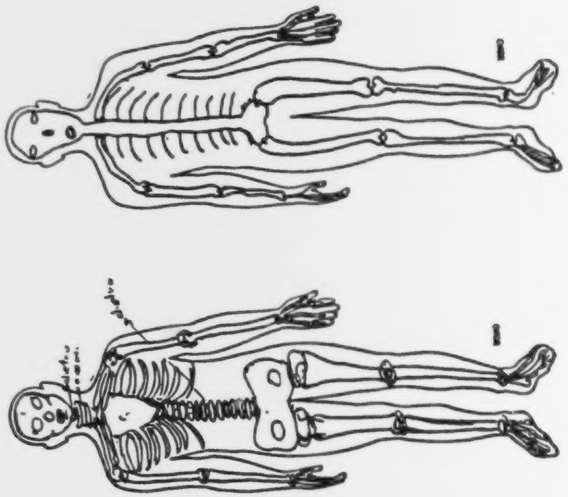

FIG.1 - These drawings were produced by a middle school student (left) and by a 4th grade student (right);both were included in the category of"essentially functional skeletons".

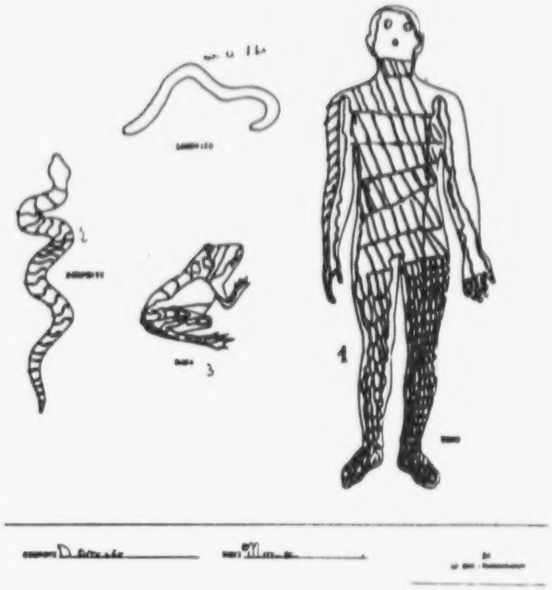

FIG.3 - This drawing of the human skeleton is representative of the type B, the "stuffed in-type".

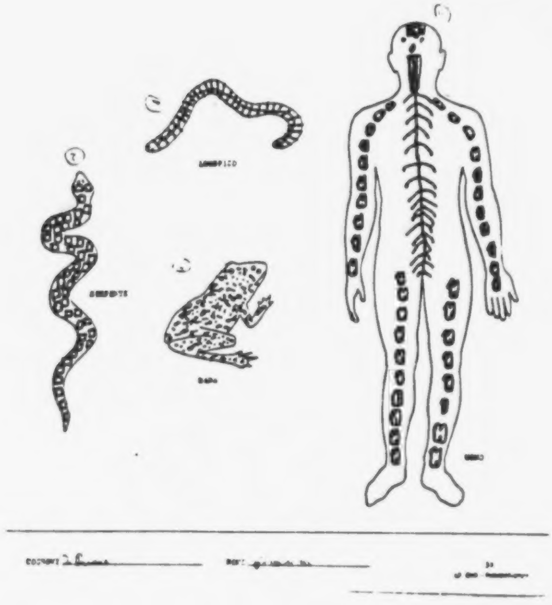

FIG. 4 - This drawing is representative of the type C,the "semi organized pieces or bones-type".In other exemplars pieces can be less regularly arranged, anyway it is interesting to notice that the pieces are placed inside the limbs.

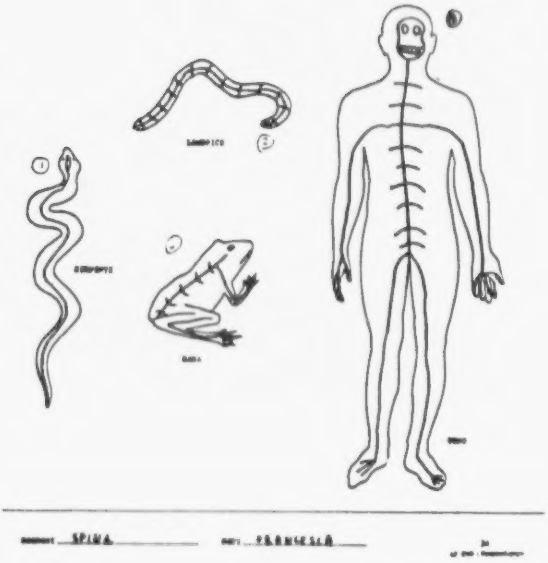

FIG. 5 - A type D drawing,the 'iron wire core' model. Notice how the same model is applied to all the other animals,a snake,an earthworm, a frog.

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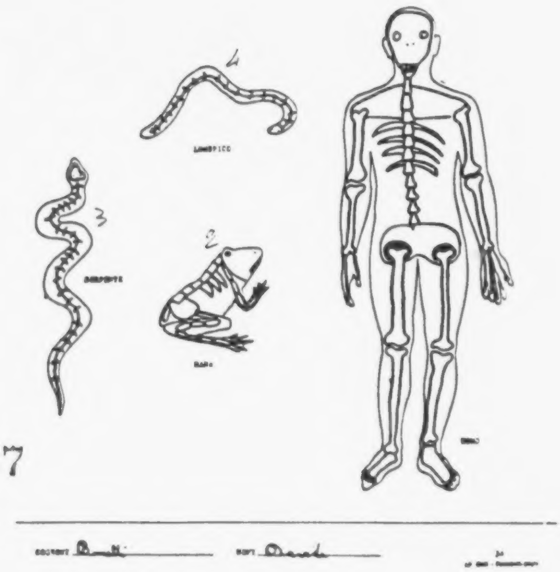

FIG. 6 - A drawing of the E type, the one which best correspond to the scientific representation of the human skeleton. Notice how the model is not generalized to the animals.

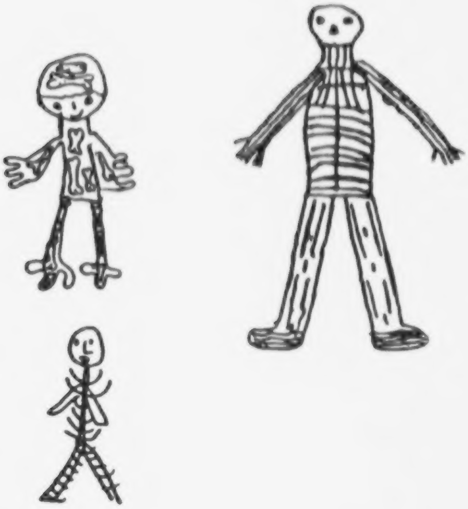

FIG. 7 - Drawings produced by 2nd grade pupils on white work-sheets (see the task sequence with a restricted sample of classes in the Appendix). Most of the children represent also the external shape of the body.

Interview Studies in Teacher Education

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"The weight of the weight, weighs 15 pounds" (Conder, 1984). A common approach used by researchers reporting studies about children's concepts is to use a cute or unexpected phrase to catch the attention of the reader. The sentence above, however, was collect by an undergraduate student interviewing children at a Children's Museum as part of her Science Methods class. A short excerpt from her paper will provide an idea of the information she was exposed to, and the reason the participants on this panel feel interview studies have a place in Teacher Education programs.

Prior to the phrase on "weights" Conder (1984) discussed how language was seen as a problem in teaching. "I asked them what a pulley was and they confused it with the verb pulling," she reported. In her analysis she continued, "I'm not sure (language) interferes with the children's ability to communicate with themselves and reach an understanding, but it certainly made the interviewing more difficult... There seemed to be three uses for the word weight: what they felt in their arm as they pulled the handle of the exhibit; the name of the yellow bell attached to the rope in the exhibit; and the gravitational pull on an object... You get something like, 'the weight of the weight, weighs 15 pounds'."

The following papers are by a group of faculty who have been using individual interviews of children and adults as part of their undergraduate and graduate Teacher Education programs. While each faculty member has developed his or her own particular approach and reason for using interviews with their students, there are a number of themes that run through all of the papers. This review will discuss the themes, add an additional item on publishing student reports and encourage expanding the network of faculty working in this area.

Theme - Students conducting interviews help faculty keep up with new and changing ideas: Using interview studies have led each of the faculty to continually "discover" new ideas, concepts and information about how children gain and maintain ideas about science. As role models for their own students, these faculty encourage the idea of seeing science through the eyes of one's own students. The information gained by our college students has been especially important for those faculty who have spent some of their career in small schools where there were no other faculty interested in studying concepts using interviews. The college students provide a source of intellectual stimulation.

Theme - Individual interviews by college students acts as a motivator for the idea that teachers need to be learners: Preservice and inservice teachers are concerned with "teaching." They often just want to know the best way to teach a particular topic. Interview studies are an excellent way to help preservice and inservice teachers think about how they and the children they teach think about science. Once they learn how easy it is for them and their students to misunderstand science concepts, they begin to think less about "teaching" and more about how learning takes place. They move from technicians, who know a few educational tricks, to professionals who continually learn about science and teaching through their interaction with their students.

Theme - The format of the interview: The formats used by the various faculty are surprisingly similar in form if not exact content. All require the students to select and learn about the topic to be studied in the interview. A set of tentative questions and branching responses to the questions is encouraged. The method of reporting varies, but usually requires the students to attempt some classification of the responses obtained through the interviews. Concept maps, charts of responses and other techniques are used. Most important for all the faculty is the student's ability to analyze the data and relate their results to their teaching and how they can help children learn. As included in the excerpt by Condor above, the majority of college students are capable of this requirement.

This is, however, one area where research into the value of this technique in Teacher Education is needed. For example, we are aware of several changes in our students ability to ask questions. The improved questioning techniques we observe involve:

1. Better listening on the part of the students. They can respond to children's questions and answers;
2. The acceptance of multiple interpretations of answers;
3. A look to the response or activity, not the teacher or authority, to sort out answers;
4. An improved understanding about science and acceptable answers;
5. An improved understanding about learning and the idea that one doesn't learn only from correct answer. Incorrect ideas can also lead to a better understanding of a concept;
6. An awareness of the fear of being wrong on an individuals ability to answer questions;
7. An acceptance that children often "make up" answers and that they, as teachers, also make up answers.

Theme - The implications for teaching and learning: This is probably the most important theme from the point of view of the faculty. Because we see our students frequently while they are conducting their interviews, we are continually bombarded with questions about science and how people think about science. In our attempts to answer their questions we try new and different methods of explanation. We also look at new and different ways to organize our courses and the Teacher Education programs in which we work.

An additional theme: The use of interviews in an undergraduate methods class is not really unique. Many students in psychology or other education classes often conduct various studies of children. How are these different? One answer is that the studies described here do not replicate standard studies. There are so many areas in teaching science, that many topic our students select have little published findings. As a result, we have been able to publish some of our students work in a state science teacher's journal and present their work at professional meetings (Bourke, 1984; Carter et al, 1981; Fuson, 1981; Orem, 1980; Truax, 1981). The fact that students' interview studies conducted in the science methods course were published became an important part of the assignment. It increased the credibility of the assignment. Here was an opportunity to create knowledge and ideas for others. This became an excellent motivator and opened many discussions on the role of the classroom teacher as a researcher.

In addition to publishing the student's papers, recent work with museums has expanded the value of interview studies in motivating our students to conduct additional interview studies as part of their class assignment. The museum staff has been very cooperative. They need to find out the value of their exhibits and explanations on the exhibits. They help our students fit into the museum setting, answers questions about the content of the exhibit, and help suggest questions and explanations. They read our student's papers, after they have been graded, and even come to our class during our discussion of the papers. They have used our student's findings to change and even remove ineffective exhibits.

The publishing of student's papers will continue to be a valuable activity. But there is always a delay between the time a paper is finished in class and published in a journal. Often students were not aware their colleagues had published the results of our class projects. With the museum studies the results were immediately reported by the museum staff. In all cases the students were able to see the importance of their "research." And for the typical elementary education major, who is not yet sure of the power they have to change or improve an educational setting, this is an important lesson.

Networking: The faculty participating in this panel have been working together for several years and are aware of the value of networking. They would be pleased to share their experiences with others. Please feel free to contact any of them. They are: Charles R. Ault, Jr., Lewis and Clark College, Portland Or.; Michael R. Cohen, Indiana University, Indianapolis, In.; Christine Kuehn, University of South Cariolina, Columbia, S.C.; Larry B. Flick, University of Oregon, Eugene, Or.; Joseph Stepans, University of Wyoming, Laramie, Wy.; Gilbert Tweist, Clarion University, Clarion, Pa.

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A DESCRIPTION OF THE STRATEGIC KNOWLEDGE OF EXPERTS SOLVING TRANSMISSION GENETICS PROBLEMS

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Introduction

Problem solving is an essential aspect of critical thinking, a topic of interest to educators and to the public. If reports such as Science and Mathematics in the Schools: Report of a Convocation (National Academy of Science, 1982) are any indication, problem solving is a topic of special interest to science educators. Concurrent with this interest is the problem-solving research of cognitive scientists that provides science educators with insights into the nature of problem solving and which holds promise for educational practice.

One research approach used by cognitive scientists has been to study the problem-solving performance of experts in content-rich domains, especially physics. In an early study, Bhaskar and Simon (1977), studying an expert in thermodynamics, noted the consistent use of a single problem-solving strategy, means/ends analysis. They also noted that the expert was consistent in performing a check of the solution. Chi, Feltovich, and Glaser (1981), comparing experts and novices solving mechanics problems, found that experts describe a problem in terms of the concepts of mechanics rather than in terms of incidental surface features. Larkin (Larkin & Rainhard, 1984; Larkin & Reif, 1979) claims that physics experts begin solving a problem by constructing descriptions of the problem at several levels. These levels include a basic description taken from the facts of the problem statement, a scientific description which converts the facts to scientific concepts, and a computational description which reduces the relationships of the concepts to mathematical formulae. In a summary of their research on the problem-solving performance of physics experts, Larkin, McDermott, Simon, and Simon (1980) identify four characteristics of expert performance: 1) the conceptual knowledge of the expert is stored and retrieved hierarchically; 2) experts have ancillary knowledge of when and how to use the conceptual knowledge; 3) they begin to solve a problem by redescribing the data given in the problem statement in conceptual terms and mathematical relationships; and 4) experts, solving typical problems, use a forward-working, knowledge-producing strategy such as setting subgoals.

Synthesizing much of the research in problem solving in physics and providing a framework for further research, Reif (1983a, 1983b) has designed a master model for understanding and teaching problem solving in any natural science discipline. The master model includes a model of desired performance derived from descriptions of expert performance, a model of novice performance, a model of learning and a model of teaching. The two components of the performance models are the two types of knowledge required to solve problems, which Reif designates as content knowledge and strategic knowledge. He identifies three aspects of content knowledge: 1) the concepts and principles of the discipline, 2) the ancillary knowledge of when and how to use this conceptual knowledge, and 3) the structure of this knowledge. He also identifies three categories of strategic knowledge: 1) data redescription strategies which enable the solver to identify the essentials of a problem and limit the problem space, 2) solution synthesis strategies by which the solver plans and executes ways to search the problem space, and 3) solution assessment strategies by which the solver decides if the answer is as complete and accurate as possible.

Although physics was the first science discipline in which problem solving was studied, transmission genetics is another area that is receiving increased attention from science education researchers. Paralleling the research in physics, Smith and Good (1983, 1984a, 1984b) have described the strategies of experts solving genetics problems. They identified 32 tendencies that can be used to differentiate between expert (or successful) and novice (or unsuccessful) problem-solving performance in genetics. Among the tendencies of experts that they identified are: 1) that the experts perceive a problem as a task requiring analysis and reasoning; 2) that they use knowledge-producing (forward-working) strategies, including setting subgoals; 3) that they begin solving the problem by investing initial time in qualitatively redescribing the problem; 4) that they make frequent checks of their work; and 5) that they use accurate bookkeeping procedures. Smith and Good found that experts also have a fund of accurate genetics knowledge which includes models of procedures for problem solving.

Although the problems studied by Smith and Good were challenging since they required the solver to analyze data about offspring and infer the genetic causes of the offspring data, the problems were taken from textbooks. Typically, textbook problems tend to be well-structured and require relatively few, recently taught concepts. Real problems in science tend to be ill-structured with many concepts, often including some that are irrelevant. The area in which the performance of experts solving real problems has been studied is medical diagnosis. Elstein, Shulman, and Sprafka (1978) have identified several characteristics of medical diagnosticians who were judged by their peers to be highly successful. These characteristics include: 1) that they are not limited to the cues (data) in the original problem situation but continuously produce additional data; 2) that the strategy used most often to make a diagnosis (solve a problem) is hypothesis testing; 3) that expert diagnosticians entertain several hypotheses simultaneously; and 4) that hypotheses are confirmed, revised or discarded in light of additional data.

Computer simulations make it possible to create realistic problem-solving environments in which the problems are ill-structured like real problems without the difficulties, such as cost and time, usually associated with real problems. Real problems in transmission genetics are not only ill-structured but also differ from typical textbook problems in form. In textbook problems, the solver is presented with a description of a trait (for example, height in pea plants) and variations (for example, tall and short) of parents and the inheritance pattern (for example, simple dominance) controlling the production of offspring. Given the limited, static data, the solution is to predict the distribution of the variations among the offspring (3/4 of the offspring will be tall and 1/4 of the offspring will be short). To reach a solution requires cause to effect reasoning, that is, from the inheritance pattern to the distribution of variations among the offspring. In real genetics problems the researcher begins with observations about a population of organisms. The researcher selects parents with traits and variations of interest (decides what the problem is) and produces generations of offspring (data) until an inheritance pattern can be inferred. To reach the solution requires effect to cause reasoning. Realistic, computer-generated problems in genetics, such as problems generated by GENETICS CONSTRUCTION KIT (Jungck & Calley, 1984), provide an opportunity for students to learn to solve problems with the form and lack of structure of real problems.

Stewart (in press) claims that the greatest potential for students achieving four important learning outcomes in science is by learning to solve realistic problems. The four learning outcomes are: 1) knowledge of the concepts of a discipline, 2) the ability to recognize and use general problem-solving strategies, 3) the ability to use these general problem-solving strategies in instances specific to a discipline and to recognize and use problem-solving strategies that are discipline specific, and 4) to understand the nature of science. In genetics, solving realistic problems provides students with opportunities to pose the problem, to use their knowledge of genetics to generate and evaluate data, and to arrive at justifiable explanations of their solutions.

A description of the strategic knowledge of experts solving realistic transmission genetics problems can contribute to the theoretical knowledge about problem solving in science by providing insights into the characteristics of successful problem-solving performance in realistic genetics problems. Description of the strategic knowledge of experts can also provide science educators with initial help in designing instruction to enable students to learn to solve realistic problems.

The primary purpose of this paper is to describe the problem-solving strategies of experts solving realistic, computer-generated, transmission genetics problems. A secondary purpose is to suggest implications for instruction in solving realistic genetics problems.

Methods

GENETICS CONSTRUCTION KIT (GCK) (Jungck & Calley, 1984) was the strategic simulation program used to generate realistic transmission genetics problems. The simulation begins by displaying a population of field-collected organisms with the sex and phenotype of each individual identified. The solver then selects individuals for parents and crosses them to produce offspring. Generations of offspring can be produced until the solver is able to infer the inheritance pattern operating on the population. Inheritance pattern is the term used to summarize the genetics knowledge required to match a phenotype (the trait and variation observed, for example green pea pods) with the genotype (the abstract, theoretical genetic factors causing the variation, often a pair of alleles expressed as paired symbols such as "Gg"). For each trait in a problem there must exist an inheritance pattern and inheritance patterns are mutually exclusive. The most common inheritance patterns taught in introductory biology are simple dominance, codominance, and multiple alleles. After the inheritance pattern has been inferred, the solver may decide that a modifier is also operating on the population. Modifier is the term used to describe the influence of the position of the alleles on the chromosome on the distribution of the phenotypes within an inheritance pattern. Modifiers do not affect the phenotype to genotpe match of the inheritance pattern. Modifiers cannot exist independently of an inheritance pattern and more than one modifier may affect a single inheritance pattern at the same time. The modifiers usually taught in introductory biology include sex linkage and autosomal linkage.

GCK can be programmed to generate populations of many types of organisms. In this study the phenotypes of the organisms were traits with the variations of insects. In a GCK problem an individual may have up to four traits. GCK organisms are diploid with homogametic females and heterogametic males. With GCK it is possible to construct problems with the following phenomena within the domain of classical Mendelian or transmission genetics: 1) simple dominance (dominance-recessiveness); 2) codominance; 3) sex linkage; 4) pleiotropy; 5) epistasis and other gene interactions; 6) lethality; 7) multiple alleles; 8) penetrance; 9) autosomal linkage, synteny, coincidence and interference; 10) multifactorial inheritance with and without environmental effects; and 11) complex combinations of most of the preceding phenomena (Jungck & Cally, 1986).

The parameters actually used to construct classes of problems were: number of traits--two; inheritance pattern--simple dominance, codominance, or multiple alleles; modifier--sex linkage or autosomal linkage. These classes of problems were chosen because they are typical of those used in high school and undergraduate biology instruction.

Seven experts solved realistic GCK-generated problems. All of the experts have a doctoral degree and experience in both teaching and research in genetics. Experts were chosen to represent a variety of interests within genetics: population genetics, clinical genetics, molecular genetics,

genetics and evolution, viral genetics, genetics and paramecium behavior. Each expert spent an hour with the researcher learning the mechanics of the computer program. At this time the experts were given the list of phenomena possible for problems generated by GCK, but were not told the parameters actually used in constructing the problems they were about to solve. After the initial hour, in order to eliminate discomfort and/or silent clues possible if the researcher were present, each expert spent four additional hours alone solving problems. Because the experts worked at their own pace and because the problem generator was random, every class of problems was not addressed by every expert and some experts did more than one problem in a class. The classes of problems attempted by each expert are presented in Table 1.

Insert Table 1 about here

In the initial session with the researcher, the experts were also asked to think aloud while solving the problems. They were given written directions on thinking aloud such as "Don't mumble." On the written directions were questions to ask themselves, such as "Why are you making the cross you are making?" with suggestions of points in the problem-solving process to remind themselves to think aloud, such as while the program is producing offspring from a cross. It was also emphasized that the transcripts of the tapes of them thinking aloud provide part of the raw data of educational research, and that too much data is preferable to too little data. Evidence that this idea was readily understood by the experts is that all of the tapes have an almost continuous, relaxed flow of comments. Without direction, all of the experts addressed the researcher while thinking aloud. The transcripts were a rich data source.

Two types of data were available for analysis and the description of the strategic knowledge used by the experts: 1) the transcripts of the think aloud protocols and 2) the computer printouts of the sequence of crosses made by each expert for each problem (the printout includes the expert solver's solution and the computer-generated solution). These data are termed research data to distinguish them from the data about offspring generated by the expert while solving the problem, which are termed problem data. A sample protocol and a sample printout are found in Figures 1 and 2 respectively. The protocol and printout belong to the class of problems, a two-trait problem with a simple dominant inheritance pattern and no modifiers, which will be used as an example in the analysis.

Insert Figures 1 and 2 about here

Analysis

The analysis and reduction of the data gathered from the performance of experts solving realistic genetics problems occurred in four stages. The first stage was to express the research data in terms of the concepts and principles of transmission genetics and group them into one of three categories: 1) about the problem data; 2) about a hypothesis that explains the results of a single cross, called a specific hypothesis; and 3) about a hypothesis about the inheritance pattern that could explain all the crosses and predict the results of additional crosses, called a general hypothesis. This first stage of data reduction required four steps. The four steps of the first stage of data reduction for the initial population and first cross for the example problem are shown in Table 2. Step 4 was to illustrate the dynamic, nonlinear nature of the solution process.

Insert Table 2 about here

The second stage in the reduction of the research data was to tabulate all the data refined in the first stage for all solvers for one class of problems. A table was constructed for each cross. Table 3 is the table for the first cross for all experts for the simple dominant problems they did.

Insert Table 3 about here

Comments about problem data are coded in the row labeled redescription. If there was a comment on the number and types of variations, the code is "v." Comments on the number of classes of phenotypes are coded "c." Comments on missing classes of phenotypes are coded "m." If the expert used symbols such as letters instead of words to discuss the traits or variations, the symbol row is marked. For example, in Table 3, in the first column, the solver quoted refers to the straw, lobed class of phenotypes as the "SL group." Comments about general hypotheses were coded. For example, SD is the code for simple dominant. To code the research data about the specific hypotheses, a chart was constructed of six possible crosses based on the phenotypic variations of the parents and the offspring produced. Each cross was assigned a letter which was used for coding. For example, specific hypothesis C is the cross of a homozygous (individuals with like alleles, aa) recessive parent with another homozygous recessive parent producing offspring with one variation the same as the parents. Specific hypothesis F is the classic Mendelian cross of heterozygous (individuals with unlike alleles, Aa) parents producing offspring with two variations in a 3:1 ratio. The row labeled type of cross was a quick reference to the parents having the same variation (L for like) or different variations (U for unlike). Observations about the research data that were not easily coded were noted in abbreviated form in the last row.

In the third stage of analysis, the data tabulated in the second stage were combined to describe the performance of all the experts for each class of problems. The descriptions were grouped into the three categories of strategic knowledge. Table 4 is the summary of the research data about problem data redescription for simple dominant

problems; Table 5 is the summary of research data about hypothesis testing, the solution synthesis strategy used in simple dominant problems; and Table 6 is a summary about confirmation, the solution assessment strategy used in simple dominant problems.

Insert Tables 4, 5, and 6 about here

The fourth stage of the analysis was to combine all the research data about the strategic knowledge of experts solving all the classes of problems considered in this study. The result of this analysis is the description of the strategic knowledge of experts solving realistic computer-generated transmission genetics problems which follows.

Data redescription. Recall that the function of data redescription is to isolate the essentials of the problem and limit the problem space. The experts include in their data redescription statements about the number and name of the traits and variations. They also combine individuals with the same phenotypic variations and consider classes of phenotypic variations and consider classes of phenotypes. Identifying the number of variations for each trait and the number of classes of phenotypes is helpful in hypothesizing about the inheritance pattern. In addition, the experts note any missing classes of phenotypes. For example, one expert says ". . . there are eleven different kinds, we've got eyes and bristles. There are only two types of bristles, hairless and singed, but for eyes we've got apricot, red, plum . . . Now what combination is not there . . . Let's count up . . . There are 1, 2, 3, 4, 5, kinds of females and 6 kinds of males. So we're missing a class of females." A missing class of phenotypes by sex among the offspring of a cross may indicate that the sex linkage modifier is operating in that population. A missing class of phenotypes by variation or an unbalanced distribution of individuals by variation is an indicator that the autosomal linkage modifier might be operating in the population.

Data redescription always precedes the formulation of a hypothesis about an inheritance pattern or modifier. Therefore, for example, data redescription occurs at the beginning of the problem. One person begins "In this problem I suppose that all three genotypes are expressed as different phenotypes for tiny, specked and sable which would mean codominant or else that there are more than two alleles at the locus." Experts also redescribe the problem data in the course of the solution synthesis whenever an alternate hypothesis is formulated. Alternate hypotheses are formulated 1) when a cross produces new data that alter the essentials of the problem, 2) when the solver is unable to infer or confirm an inheritance pattern, and 3) when solvers realize they have made an error in data interpretation. One example of new data altering the problem is, "Even before I begin I am suspicious that there is something funny because there are no b (blistery wing) males . . . I'll do a bs (blistery wing, sepia eye) female with an ss (short wing, sepia eye) male cross . . . Oh, there are b (blistery wing) males, so much for that hypothesis. Now there are 8 groups and it looks like it is simple." Data redescription also occurs when a solver considers a hypothesis about a modifier and, in a multitrait problem, when the solver begins to focus on the inheritance pattern of a different trait. In considering a modifier one expert says, "I crossed an sc (scarlet ocelli, crinkled antennae) by wb (white ocelli, blunt antennae) and Wow, yeah I got--wc's (white ocelli, crinkled antennae) are 2, sb's (scarlet ocelli, blunt antennae) are 1, sc's (scarlet ocelli, crinkled antennae) are 20 and wb's (white ocelli, blunt antennae) are 11. I can see clearly that I got an excess of parental types contributing to the heterozygotes that I used in the cross which suggests strongly that these are not independently assorting but linked."

By redescribing the data, the solver is able to limit the problem space to reasonable general hypotheses and consolidate and recall knowledge that has been obtained from the crosses that have been done so far.

Solution synthesis. Solution synthesis strategies are those used to plan and execute a search of the problem space and enable the solver to infer a solution. In realistic transmission genetics problems the solution strategy that is used by all experts is hypothesis testing. Experts formulate two types of hypotheses--general hypotheses about the inheritance patterns and modifiers and specific hypotheses about the distribution of variations to offspring for each cross. Because new data are continuously produced, there is an interaction between the problem data, the specific hypotheses and the general hypothesis. One expert begins, "I've got 4 classes each of males and females so there is no reason not to think it is simple so I'll cross the dw's (dumpy wing, white eye) with the sc's (shiny wing, cinnabar eye) and all the offspring are dw (dumpy wing, white eye), so if d (dumpy wing) and w (white eye) are dominant, the offspring are all heterozygotes . . ." In the example, the initial population data presents an organism with two variations for each of two traits. The redescription allows the expert to retrieve the knowledge needed to formulate an initial, tentative general hypothesis of simple dominance. The expert then chooses to cross parents with unlike variations, using the specific hypothesis that if the genotype of one parent is homozygous dominant and the genotype of the other parent is homozygous recessive, the offspring will be heterozygous and have a dominant phenotype to predict the distribution of variations among the offspring. This cross is then performed, and the results agree with the prediction. The newly generated data support the specific hypothesis and the specific hypothesis helps the solver infer the general hypothesis. This interaction between data, specific hypotheses, and general hypotheses continues throughout the synthesis of the problem solution. Also, in the solution synthesis, for each inheritance pattern and modifier, there is a cross or class of crosses that, once performed and explained, assures the solver that the solution is justifiable. This cross is being termed the definitive cross. In simple dominance and codominance this definitive cross is the F(2) cross; in multiple alleles the class of crosses used to justify the solution includes two F(2) crosses. An F(2) cross is between two parents that are known to be heterozygotes with the distribution of variations to the offspring in a 3:1::dominant:recessive ratio. In the example begun earlier in this paragraph the expert continues solving the problem by using the offspring from the first cross, assuming they are heterozygotes, as parents in the second cross. This is an F(2) cross for both traits. The definitive cross in all classes of problems except sex linkage requires the identification of heterozygous individuals. In this problem the expert has constructed heterozygous individuals by crossing parents with unlike phenotypes.

Once the inheritance pattern has been inferred, the expert continues to do crosses to decide if a modifier is operating on the population. Either because of indicators in the problem data and/or to assure themselves the solution is complete, experts usually consider both sex linkage and autosomal linkage modifiers. In testing for modifiers, the interaction between the problem data, the specific hypotheses and general hypotheses continues. There is also a definitive cross to justify each modifier. In sex linkage the definitive cross is between a dominant male and a recessive female, producing recessive male and dominant female offspring. In the two-trait autosomal linkage problems the definitive cross is between a parent that is heterozygous for both traits and another that is homozygous recessive for both traits. The indication that the traits are not independent is that the ratio of the distribution of the variations to the offspring is not the expected 1:1:1:1 ratio.

By formulating two types of hypotheses, and by generating additional data that are either explained by a hypothesis or predicted from a hypothesis, experts are able to infer solutions to genetics problems that are justifiable.

Solution assessment. Solution assessment strategies are used to assure the solver that the solution is as complete and accurate as possible. While determining the presence of a modifier in the problem, the experts are assuring themselves that the solution to the problem is complete.

Experts assure themselves that the solution is accurate by confirmation, by collecting additional evidence beyond the definitive cross that they have reasonably inferred the inheritance pattern or modifier. Although the Chi square test is the statistical test to determine if the observed distribution of variations to offspring agrees with the distribution expected from the principles of transmission genetics, experts seldom use the Chi square test. Rather, they compare the ratios of the distribution of the variations by intuition, without the formal mathematical test. Experts also increase their confidence in the accuracy of the inheritance pattern and modifier hypotheses by doing additional crosses that are explained by or predicted from the general and specific hypotheses. Whenever possible, experts use more than one method of confirmation. One example of confirmation is, "I think now I'll do its reciprocal." Another expert says, ". . . this is basically the 9:3:3:1--20:9:5:2, which is very, very, very close. So I'm sure I know what is going on already. Might as well confirm it by a test cross." A third example of confirmation is the expert who says, "I think I'll just repeat that cross a few times to jack up the numbers before I pull out my calculator . . . Oh, the ratio is getting closer all the time."

By using mathematical tests and by generating additional data, solvers increase their confidence in the completeness and accuracy of the solution to each problem.

Summary. The description of the strategic knowledge of experts used to solve introductory-level realistic transmission genetics problems is summarized in Table 7. The strategy of data redescription consists of identifying traits, variations and classes of phenotypes and their distribution. It occurs prior to the formulation of tentative general hypotheses. The strategy of solution synthesis is hypothesis testing. Hypothesis testing in the classes of problems considered requires a definitive cross usually using heterozygotes. The strategy of solution assessment consists of producing additional evidence to confirm the inferred hypothesis. Experts in genetics know when and how to use these strategies to successfully solve realistic problems. The solution is the identification, by inference from the problem data generated, of general hypotheses about inheritance patterns and modifiers. The expert, having tested and confirmed the hypotheses by using them to explain and predict data, has a high degree of confidence that they are justifiable from the data.

Insert Table 7 about here

Table 8 summarizes the genetics feature of each category of strategic knowledge used by the experts to infer the solution for each class of problems. For data redescription this feature is the characteristic of the problem data that the solver used initially to limit the problem space. For solution synthesis this feature is the definitive cross used by the experts to justify the inheritance pattern or modifier. For solution assessment this feature is the method of confirmation most frequently used for that inheritance pattern.

Insert Table 8 about here

From the analysis of the research data on the performance of experts solving realistic computer-generated transmission genetics problems, the description of this performance can lastly be summarized as a flowchart, Figure 3. In this flowchart there are many paths and many feedback loops but the three categories of strategic knowledge used in solving genetics problems--data redescription, hypothesis testing and confirmation--regularly recur. From the flowchart it is also evident that the opportunity to continuously produce problem data is essential for the solution of these realistic problems.

Insert Figure 3 about here

Implications

From the description of the strategic knowledge of experts solving realistic transmission genetics problems one implication can be made about the utility of the model designed by Reif as a starting place for the study of problem solving in science. The categories of strategic knowledge identified by Reif to describe problem solving in physics--data redescription, solution synthesis and solution assessment--have been used to describe problem solving in transmission genetics. The details within each category are different for genetics problems and physics problems, but this is expected since the disciplines are different, and the realistic problems studied in genetics are not like the textbook problems studied in physics in structure and form. Among the differences are: 1) that in the physics problems the data are limited to what is given in the problem statement while in the genetics problems continuous data production is possible, 2) that in the physics problems the solution requires a mathematical formula while no mathematical formula exists for the solution of the genetics problems, and 3) that in the physics problems the solution has a numerical value while in the genetics problems the solution is a confirmed hypothesis. The fact that the genetics problems and physics problems are not similar but that the same categories of strategic knowledge can be used to describe problem-solving performance in both disciplines, supports the utility of the model.

A second implication is about the content knowledge of expert problem solvers in genetics. This implication may be important both to the study of problem solving and to the design of instruction in problem solving in science. Although content knowledge is not the emphasis of this study, it is evident that expert problem solvers in genetics have a large store of compiled, easily retrievable information available for problem solving. The use of strategic knowledge could not be described without reference to the content knowledge--for example, of inheritance patterns and modifiers, of specific crosses, of traits and variations, of dominant and recessive variations, of phenotypes and genotypes, of homozygotes and heterozygotes. It is also evident that this content knowledge includes information of when and how to use the strategic knowledge. For example, the experts know that an F(2) cross yields data useful in testing the simple dominant inheritance pattern hypothesis, and that this cross requires heterozygous individuals. In the study of problem solving, further research is needed to analyze and explicate the content knowledge required for successful problem solving in genetics. Likewise, instruction designed to teach problem-solving strategies in genetics cannot be independent of instruction in the content of the discipline.

Another implication important for the design of instruction in problem solving in genetics is the need to include clear and explicit information on the use of each of the three categories of strategic knowledge. Teaching problem solving using realistic, computer-generated problems is currently an atypical experience for an instructor. Even though the instructor may have more knowledge and experience than the students, the instructor does not know the correct

answer before beginning the problem. The instructor becomes a co-researcher with the students. In the context of solving realistic problems, the instructor and the students explore the problem together. However, since strategic simulation programs have only recently become available, neither instructors nor students have much experience in solving realistic problems. This is a realistic time to try to improve instruction. Data on how students solve realistic problems without instruction can contribute to the design of new instruction. Research by Albright (1987) and Slack (1987), using GCK problems, is in process to describe the strategic knowledge of novices at the high school and undergraduate biology levels. They are finding, for example, that novices do not begin GCK problems by identifying important aspects of the problem data (redescription). It is reasonable that instruction in solving realistic genetics problems includes knowledge of the general strategy of redescription and specific details for redescription in solving genetics problems. If students are to realize the full benefits of learning to solve realistic genetics problems, it will not be sufficient for the instruction to merely identify strategic knowledge being used in the process of seeking a solution; reasons for its use will have to be clearly and explicitly identified. For instance, students may learn that it is important to identify the name, number and distribution of traits, variations and classes of phenotypes for data redescription at the beginning of a problem, but to be successful problem solvers, students also need to learn the content knowledge that explains why this information is useful in limiting the number of possible justifiable solutions.

As science educators work to design instruction for solving realistic problems, the development of artificial intelligence computer programs will affect what is produced. MENDEL (Streibel, Stewart, Koedinger, Collins, & Jungck, 1987) is an artificial intelligence computer tutoring system for genetics problem solving. MENDEL has two computer program components: the GCK problem generator and a TUTOR. The TUTOR, in turn, includes a SOLVER program and an ADVISOR program. The SOLVER consists of frames that contain content knowledge and rules, derived from this study of expert performance, for the use of strategic knowledge. The design of the ADVISOR addresses some of the same instructional issues as the design of traditional classroom instruction. These include what strategic knowledge to teach and when and how to teach it and how to integrate instruction in strategic knowledge and content knowledge.

The advent of realistic, computer-generated problems has created opportunities for students to achieve important learning outcomes in science. As models for understanding and teaching problem solving develop and as technology makes the computer a powerful and available instructional tool, science educators need to continue to design instruction to provide students with improved learning experiences in problem solving. One step on toward achieving the goal of improved instruction and learning in problem solving is to describe the performance of successful problem solvers.

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Table 1
Classes of Problems Attempted by Each Expert

Problem	Expert 1	2	3	4	5	6	7	Total
Simple dominance	2	2	2	2	2	2	2	14
Codominance	2	2	1	2	2	2		11
Multiple alleles	4	1		1	1	2		9
Sex linkage	1	1	2	1	1		1	7
Autosomal linkage	2	1	1	1		1	1	7
Total	11	7	6	7	6	7	4	48

Table 2
Stage One: Data Reduction - Simple Dominance

Cross	Step 1: Read the transcript and mark it to correspond with the crosses	Step 2: Place the phrases of the transcript in groups depending on whether they refer to problem data (PD), specific hypothesis (SH), or general hypothesis (GH)			Step 3: Reduce the phrases of the transcript to transmission genetics concepts and add notes			Step 4: Draw arrows to represent the sequence and relationship of (PD), (SH), and (GH)
0	We're back to 8 phenotypes and 2 groups of characteristics yellow and straw and red and lobed. Start with a simple dihybrid cross. We'll just for fun assume that the least frequent phenotype is going to be doubly recessive and do it.	PD 8 pheno 2 group charact yellow & straw red & lobed	SH least frequent is doubly rec.	GH simple dihybrid	PD classes traits variations	SH aa x aa → aa double note lfp = rec	GH simple dom	PD SH GH → →
1	I'll start with an SL by SL mating and we got all SL's. That's helpful.	PD all SL	SH SL x SL mating	GH helpful	PD traits	SH aabb x aabb → aabb	GH confirm SD	← →

Table 3
Stage Two: Data Tabulation - Simple Dominance

Cross 1														
Person	1		2		3		4		5		6		7	
Problem	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Redescription		m	v		c v not like real	c							m	
Symbol	x		x	x							x	x		
General hypothesis	SD	other SD			SD		SD		SD		SD	SD		SD
Specific hypothesis	C	C D			E		c		F		C	C		C/A D
Type of cross	L	L U	U	U	U	L	L	U	U	L	L	L	L	L
Notes		separate traits ratio sex ratio	series	separate traits sex ratio create het	separate traits ratio create h cross error	ratio sex ratio cross error		separate traits ratio create het create miss class	separate traits	have hypo but no confirm	separate traits missing class		sex ratio series	separate traits

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Table 4
Data Redescription--Simple Dominance

1. Details of Initial Redescription
    - -- 14 of 14 problems have some type of initial redescription
        - -- 10 include comments on traits, variations and classes of phenotypes
        - -- 2 include comments on traits and variations
        - -- 2 include comments on the number of classes of phenotypes
        - -- 5 note missing classes
        - -- 4 note least frequent phenotypes; of these, 1 also notes most frequent phenotype

2. Additional Occasions of Redescription
    - -- 2 problems are redescribed when the attention of the solver is focusing on the second trait
    - -- 6 problems are redescribed whenever an alternate hypothesis is considered
    - -- 4 problems are redescribed at the end of the problem

Table 5
Solution Synthesis--Simple Dominance

1. Origin of the General Hypothesis
    - -- 6 problems have the simple dominant inheritance pattern stated from the redescription of the initial population
    - -- 6 problems have hypothesis stated after 1 or 2 crosses
    - -- 2 problems have hypothesis stated after beginning a series of 4 or 5 possible crosses

2. Definitive Cross
    - -- In 8 of the 11 successfully solved problems a monohybrid or dihybrid F(2) cross is used to match genotype to phenotype
        - -- In 2 of these the heterozygote is constructed
        - -- In 6 an obligate heterozygote is located
    - -- In 3 of 11 successfully solved problems the linkage cross is used to match genotype to phenotype
        - -- In 3 an obligate heterozygote is used

3. Alternate Hypotheses
    - -- In 11 problems autosomal linkage as a modifier is considered and rejected
        - -- 11 times after the inheritance pattern is confirmed
        - -- 7 times by the linkage cross
        - -- 4 times by a dyhybrid F(2) cross

table continues

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Table 5, cont.

- In 10 problems the sex linkage modifier is considered and rejected
  - 6 times after the inheritance pattern is confirmed
  - 2 times after the second cross
  - 2 times it is rejected by the sex linkage cross
  - 8 times the hypothesis is rejected because there is nothing to support it
- In 1 problem lethality is rejected because there is nothing to suggest it
- In 4 problems other hypotheses are considered--sex influence, sex limited and interaction

---

Table 6
Solution Assessment--Simple Dominance

1. Mathematical
   - In 8 of the 8 problems that use an F(2), ratios are used to confirm the inheritance pattern and genotype to phenotype match
     - In 1 problem Chi square is used
     - In 7 problems the solver says the ratio "looks ok"
     - In 3 problems Chi square is mentioned but not used

2. Strategic
   - In 6 problems both an F(2) and a linkage cross with an examination of their ratios are used to confirm simple dominance
   - In 4 problems the definitive cross is repeated with different individuals, in 1 case the reciprocals of the F(2) cross
   - In 9 of 11 problems at least two methods of confirmation are used

---

Table 7
Summary of the Characteristics of Strategic Knowledge

1. Data Redescription
   - Consists of
     - number and name of variations
     - number and name of traits
     - number of classes of phenotypes
     - missing classes of phenotypes
     - unequal distribution of individuals to classes of phenotypes
   - Occurs prior to formulation of a general hypothesis

table continues

Table 7, cont.

2. Solution Synthesis
   - Consists of hypothesis testing
     - general hypotheses about inheritance patterns and modifiers
     - specific hypotheses about crosses
   - Occurs by
     - using hypotheses to explain data generated by crosses
     - predicting new data by crosses from hypotheses
   - Requires
     - interaction of data, specific hypotheses and general hypotheses
     - performing a definitive cross using heterozygotes

3. Solution Assessment
   - Consists of confirmation
   - Occurs by collecting additional evidence
     - through Chi square and other informal mathematical tests
     - by doing additional crosses
   - Includes more than one form of confirmation if possible

Table 8
Summary of Details of Strategic Knowledge

	Redescription	Solution Synthesis	Solution Assessment
	Characteristics	Definitive Cross	Confirmation
Simple dominant	2 variations/ trait	F(2)	Chi square linkage
Co-dominant	3 variations/ trait	F(2)	Chi square linkage
Multiple alleles	3-6 variations/ trait	Series of crosses with an F(2)	Match all phenotypes to a genotype
Sex linkage	Missing class of phenotype of one sex	Dominant m X recessive f	None
Autosomal linkage	Missing or low frequency class of phenotypes	Linkage	Repeat cross with different individuals

Figure 1. Transcript of think aloud protocol for simple dominant problem.

Well, fortunately we're back to 8 **phenotypes** and two groups of **characteristics**.

Yellow and straw and red and lobed.

Start with a **dihybrid** cross.

We'll just for fun assume that the least frequent **genotype**, **phenotype** is going to be doubly **recessive** and do it.

That means it's SL.

I'll start with an SL by SL mating.

And we got all SL's.

That's helpful.

Let's try a YR by SL cross and then do an F(2).

If it works the way I'm expecting.

OK YR by SL gives uh only YR's.

So presumably I happened to pick up a **homozygous** YR and now I have just **heterozygous** YR's.

So we should get a nice distribution by crossing them.

Let's see if this new line is basically a 9:3:3:1.

20:9:5:2 which is very, very close.

So I'm sure I know what is going on already.

Might as well confirm it.

Doing a **test cross**.

Let's see Vial 2 by Vial 3.

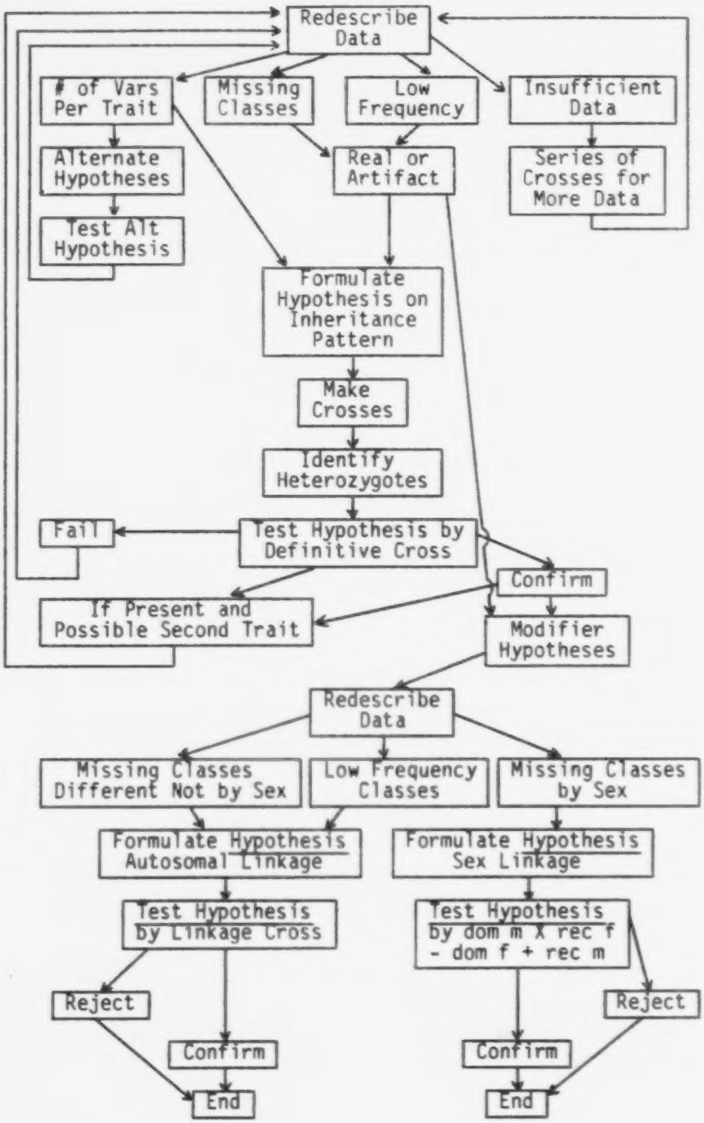
That gives a 14:10:8:8 which I'm sure is near enough to 1:1:1:1.

Y and R are **independently segregating** and are **dominant** over S and L.

Figure 2. Computer printout of simple dominant problem and solution.

```
******************* N E W   P R O B L E M *******************

                       Problem Type #1
*************************************************************

   Contents of Vial #1 (field-collected population):
 8 F  Yellow     Red                7 M  Yellow     Red
 1 F  Straw      Lobe               1 M  Straw      Lobe
 3 F  Straw      Red                1 M  Straw      Red
 2 F  Yellow     Lobe               1 M  Yellow     Lobe

Entering CROSS....
     Vial #1  Phenotype #3  Individual #1  (f SL x m SL)
     Vial #1  Phenotype #4  Individual #1

   Contents of Vial #2 (offspring from cross above):
16 F  Straw      Lobe              11 M  Straw      Lobe

Entering CROSS....
     Vial #1  Phenotype #1  Individual #2  (f YR x m SL)
     Vial #2  Phenotype #2  Individual #2

   Contents of Vial #3 (offspring from cross above):
20 F  Yellow     Red               28 M  Yellow     Red

Entering CROSS....
     Vial #3  Phenotype #1  Individual #7  (f YR x m YR)
     Vial #3  Phenotype #2  Individual #8

   Contents of Vial #4 (offspring from cross above):
10 F  Yellow     Red               10 M  Yellow     Red
 3 F  Yellow     Lobe               2 M  Yellow     Lobe
 1 F  Straw      Lobe               1 M  Straw      Lobe
 2 F  Straw      Red                7 M  Straw      Red

Entering CROSS....
     Vial #2  Phenotype #1  Individual #8  (f SL x m YR)
     Vial #3  Phenotype #2  Individual #5

   Contents of Vial #5 (offspring from cross above):
 6 F  Straw      Red                8 M  Straw      Red
 6 F  Yellow     Red                2 M  Yellow     Red
 5 F  Yellow     Lobe               5 M  Yellow     Lobe
 5 F  Straw      Lobe               3 M  Straw      Lobe

Solver's Solution:
     Dihybrid.  Alleles Y and R are dominant over S and L,
     respectively.  They appear to be completely indepen-
     dently segregating.

Program Solution:
     Trait #1 (Body):  There are 2 alleles.
     Genotypes map to phenotypes as follows:
        1,1  IS  Yellow    2,2  IS  Straw    1,2  IS  Yellow

     Trait #2 (Eyes):
     Genotypes map to phenotypes as follows:
        1,1  IS  Red       2,2  IS  Lobe     1,2  IS  Red
```

Figure 3. Flowchart of solution path used by experts to solve realistic transmission genetics problems.


Redescribe Data
# of Vars Per Trait
Missing Classes
Low Frequency
Insufficient Data
Alternate Hypotheses
Real or Artifact
Series of Crosses for More Data
Test Alt Hypothesis
Formulate Hypothesis on Inheritance Pattern
Make Crosses
Identify Heterozygotes
Fail
Test Hypothesis by Definitive Cross
Confirm
If Present and Possible Second Trait
Modifier Hypotheses
Redescribe Data
Missing Classes Different Not by Sex
Low Frequency Classes
Missing Classes by Sex
Formulate Hypothesis Autosomal Linkage
Formulate Hypothesis Sex Linkage
Test Hypothesis by Linkage Cross
Test Hypothesis by dom m X rec f - dom f + rec m
Reject
Reject
Confirm
Confirm
End
End

THE PUPIL AND THE LIVING CELL: A TAXONOMY OF DYSFUNCTIONAL IDEAS ABOUT AN ABSTRACT IDEA

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INTRODUCTION

Misconceptions concerning biological processes have been shown to be fairly common (e.g. Bell (1985), Brumby (1979, 1981, 1982, 1985), Mintzes (1984), Marek (1986), Tamir, Gal-Choppin & Nussinowitz (1984), etc;). In fact "what is needed, in order to move education on, is not more additions to the mountains of examples of children's 'alternative frameworks...' (Claxton, 1986), but efforts to provide logical bases for a deeper understanding of why pupils -- having been "taught"-- retain their preconceptions. This paper will not attempt mainly to identify the sources of pupils' knowledge as done e.g by West and Pines (1984), or classify pupils' "non - scientific views and partial understandings" in the manner offered (for physics) by Osborne & Gilbert (1980), but will suggest a basis for a taxonomy for pupils' "messy, contradictory and obstinately persistent ... out-of-school ideas" (Solomon, 1983). This basis will be the "measure of functionality" of pupils' pre- and post-instructional conceptions.

When a pupil "learns" new scientific contents these become "conceptions", only if they are functional. By "functional" we mean literally that they function, i.e. have consequences which influence the kind of logical inferences made by the pupils in relation to relevant parts of their knowledge (or the manner in which they approach relevant scientific problems)

The taxonomy which follows is the outcome of a study on pupils' post-instructional grasp of the "idea of the living cell as the basic unit of life". We regard the term "idea" as quite appropriate in this case,since the living cell is -- for pupils involved in this study, i.e. 10th. graders having been taught "the cell" in 9th. grade -- an abtract idea . Multicellular organisms from which the experience of pupils is derived, do not disclose the activity of the single cell. Pupils may observe cells, as they would observe single bricks in a building, but they cannot observe cells actually functioning, since the metabolic processes can only be inferred from experiments, but cannot be directly perceived by pupils' senses.

Since the purpose of this paper is not to present a detailed report of the study, but to make use of its results, the following outline will be kept as brief as possible.

OUTLINE OF STUDY

a) Survey of teachers', inspectors', science educators' and curriculum specialists' views of what aspects of "the living cell" should be taught at 9th. grade. (see appendix 1).

b) Condensation of these "curricular demands" into a 12 points list on which there appeared to be a general concensus.

c) Construction of an open-ended questionnaire relating to these 12 points.

The items were composed of (faulty) "pupil- science". Respondents were expected to relate to them by applying learned concepts and principles, i.e. "teacher-science", and giving valid reasons for their responses. E.g.:

Item 3: A pupil states: "There is a lot specialisation amongst body cells. We can find cells specialising in energy production and others which specialise in protein synthesis." What do you think about this?

Item7: A pupil says: "The passage of substances through the cell membranes is actually like the passage of substances through filter paper." What do you think about this?

After respondents had finished giving their views on these 12 statements of "pupil-science", they were given another answer-sheet and a page of "hints", and encouraged to change their previous responses, if they found it necessary. The relevant hint for e.g.item 7 was: The passage through filter paper depends on particle size only.

This two-phase questionnaire was administered to 219 grade 10 pupils from representative , but not too selective, schools, where the "the living cell" had been taught in grade 9.

The overall results (before hints) were 33% acceptable answers, and after hints, 40%, showing that "hinting" had been of little effect. Item results ranged from from 6% to 51% (before hints) and 9% to 60% after. The "cell specialisation" and "cell membrane" responses came to 17% and 21% respectively before, and 21% and 35% respectively after hints. The pupil responses, apart from being analysed statistically, were categorised conceptually. A representative, stratified (upper, middle and lower thirds in each school) sample of respondents, about 20% of the total, was then selected for interviewing. The following will be based on "pupil-science" uncovered by their written (tested) and oral (interviewed) responses.

CONCEPTIONS, MISCONCEPTIONS, NON-CONCEPTIONS

We will now suggest a classification of pupils' errors, as uncovered in this study , according to how the pupils arrived at their errors: what they did and what they knew, when asked to answer questions concerning the living cell.

Category a) The theory of the pupil is completely wrong; the relevance of classroom knowledge has not been recognised, and the pupil keeps using naive but effective personal knowledge. This was found to be frequent in that part of the population sample which represented pupils from educationally disadvantaged backgrounds, characteristically unable to divorce their private experience from theoretical situations, e.g.: " When children are made with much love, they receive a great amount of hereditary information and become strong and beautiful, whereas in other cases...." -- to explain that, actually, hereditary materials are not evenly divided between cells.

Category b)The impact of strong associations from pupils' experience or from every-day (non-classroom) sources remains stronger than classroom learning ; pupils do not use the scientific knowledge they have been taught, but stick to their out-of-school perceptions of phenomena or concepts e.g.: "There is a great amount of energy in water (everyone knows that when you are tired you drink water and feel much stronger)".

When pupils said that "only liquids can penetrate the cell membrane", they were not referring to molecules (a level at which the term "liquid" would be meaningless) but to their personal, naive but to them quite satisfying, perceptions of liquids as something "extremely thin". Naive anthropomorphic expressions (the cell "knows" what to ingest and what to reject) also belong to this category.

Categories a) and b) both represent cases in which the pupils had been applying personal knowledge to school situations. However category a) represents cases of pupils' ego-involvement whereas category b) does not. In both a) and b) pupils had truly generated "new" mental constructs, new (although wrong) knowledge, and -- according to their private perception -- this knowledge was perfectly sound. The "official" scientific knowledge was lacking or had not reached the level of functionality at which it would have been able to replace the naive personal knowledge of the pupils. These categories correspond quite well to the findings of Bell's (1985) study , in which most of the pupils did not "accept scientific ideas in response" to the main questions they were asked.

In the following categories , the possibility for the pupil to be personally involved becomes more remote.

Category c) The impact of strong associations with some previously acquired and in itself correct scientific knowledge, brings about indiscriminate overgeneralisations or inferences and sometimes contradictory applications of knowledge.

There were various instances and various degrees of occurence of this category e.g. the specialisation of cells in protein and energy production, which was an overgeneralisation of the fact that cells do specialise; the idea that the enzymatic breakdown of molecules in the digestive tract produces energy, inferred from the fact that energy is indeed yielded by enzymatic breakdown of molecules. Similarly, the mechanism by which the the animal body first ingests food and then digests it, was applied to microorganisms.

Category d) Quite often, the careless (see Cho Hee-Yung, Kahle & Nordland, 1985; Jungwirth, 1975), perhaps unavoidable use of "easy" words (which are often analogies), instead of the too esoteric scientific terms, brings about naive and attractive-to-pupils interpretations of biological processes: Enzymes "cut" or "build" molecules. As a result enzymes are perceived as live entities. The membrane of the cell "controls" the intake of materials by the cell: the membrane is then understood as able to receive stimuli and to react in various ways to them. Indiscriminate verbal associations bring about unsound and often contradictory inferences. For instance, calling the protein molecule (an "abstract" entity) "giant" and the microbe (another "abstract" entity) very "tiny", makes some pupils infer uncritically, that a cell can be smaller than the molecules of which it is built.

Categories c) and d) represent cases in which the pupils did possess the necessary prerequisite knowledge to learn the right scientific principles. However, this was all, using Deadman and Kelly's (1978) terms "prescribed learning", which resulted from teaching provided within the school, of which they had no private experience or perception. These prerequisites, which had been expected to prevent the drawing of wrong conclusions, had apparently just not functioned in that way. During the interviews we found that the pupils gave up these self-made theories very easily, with an indifferent "if you say so" shrug. They had so far stuck to these theories because a) they had felt no personal urge to test them; b) they did not remember ever having had opportunities to do so. From the interviewer's point of view that meant that there had been no opportunity for conceptual conflict, or dissatisfaction, or conceptual change or exchange (see Nussbaum & Novick,(1982); Posner, Strike, Hewson & Gertzog, (1982); West and Pines,(1984)). As far as the pupils were concerned, the difference between the new official principles,and their old erroneous ones was just of no consequence. The vitality of these pupil-held theories stemmed therefore from the fact that they had never, so far, been diagnosed by the teachers. The pupils had thus survived quite well -- not as scientists or as users of the theories -- but, irrelevantly from the subject matter point of view, as pupils.

Category e) Dubious but attractive and apparently sound analogies take the place of explanations which are beyond the scientific level of the pupils. Teachers often have no alternative but to accept such analogies. One of the most characteristic examples in this study was the analogy between the control functions of the nucleus of the cell, and of that the brain.

Category f) This category is very similar to the preceding one, but includes answers which teachers probably would not accept: When confronted with phenomena which they cannot understand, pupils tend to invent strange ad hoc theories (see below).

Categories e) and f) represent cases in which the pupils did NOT possess the prerequisite knowledge to understand the topics they were supposed to be learning, at least not in the manner these were being taught. In such cases, the pupils tried to explain one abstract phenomenon by relating to another , which, while already accepted for reasons of empathic familiarity, (Hempel, 1966),was in itself not understood.
Thus they had suggested the brain-nucleus analogy, for example, because, considering their total lack of knowledge, it was the best explanation they could find when required to explain something which was to them inexplicable. They knew nothing of the function of the brain, but were just familiar enough with the idea that the brain controls the activities of the body.

In a quite similar situation, the pupils had invented various erroneous explanations of the selectivity of the cell membrane. They were not too sure about them, but found them to be reasonably satisfying, for they lacked the knowledge which would have shown their fallacy, and had no way to test them meaningfully. Such pupil explanations of "abstract" biological phenomena are usually never discovered by the teachers, because they belong to an area which teachers recognise as being above the level of the pupils (the fact of the selectivity of the membrane is taught, but its mechanisms are not), so that the teachers never question pupils about them. In some cases teachers may even encourage and offer such analogies. Pupils then adopt them because of their efficacy, not in the solving of scientific problems, but in satisfying the teachers.

Their main strength of such explanations stems, as in the previous categories, from the fact that they have never been diagnosed. As with categories c) and d), interviewed pupils accepted readily and indifferently the idea that their suggestions were wrong. At the scientific level at which they were able to function, the difference between correct (official) explanations and wrong ones was of no consequences to them.

CONCLUSIONS

We have found in this study, like many other researchers, that completely wrong and often "naive" answers (categories a and b), may be authentic "conceptions", in the sense that they are private constructs of the mind of the pupils, and as such ,serve the needs of the pupils, as they perceive them, successfully. Such (mis)-conceptions may have the strength of what Polanyi (1966) has called "personal knowledge", and be "surprisingly" (see Champagne, Gunstone and Klopfer (1983) or "obstinately" (Solomon, 1983) persistent, or "amazingly tenacious and resistant to extinction" (Ausubel, Novak & Hanesian, 1978).

But this study uncovered other categories of errors, those which arise in the form of opportunistic responses to coercive classroom situations, and are not derived from pupils' personal knowledge. These errors, even if fairly common and widespread amongst pupils, should not be regarded as true conceptions (and therefore also not as true misconceptions), because they represent non-functional knowledge. As we have shown above, they are not based on wrong conceptions but rather on lack of conceptions or lack of awareness of the meaning of the scientific contents which have been taught. These errors are symptomatic of a failure of the educational system to teach "meaningful" concepts.

The main conclusions of this study can be drawn on two levels: the teaching of pupils and the teaching of concepts .

a) Most of the current literature on the teaching of concepts gives the impression that pupils at school are engaged in a pure learning activity, where naive personal conceptions interact in their minds with the new concepts they are supposed to learn. Actually, pupils at shool are interacting in various degrees with factors which are by and large irrelevant to subject-matter contents, i.e with teachers, peers, marks and examinations, self-image, social expectations, etc. They are engaged in a social enterprise , in which the positive and negative reinforcements which may cause the fixation of non functional knowledge, are very often extrinsic to the subject matter. The pupils may stick to such knowledge because, for example, conscious or unconscious teacher-behaviour has made it useful in the social context of the classroom. Non functional knowledge -- from the scientific point of view -- must therefore be diagnosed before it becomes socially functional.

b) A concept is defined by its attributes; its meaning is drawn from its logical relations with other concepts, and from its successful application in a relevant field of knowledge. However, when teaching naive pupils "abstract" and complex concepts, such as "the living cell", we may find that the attributes of the concept as well as the logically related concepts are beyond the ken of the pupils. The idea of "basic unit of life" draws its meaning from the understanding of the chemical processes which take place within the cell; so do the "role" of water in the cell and its energy needs. Without understanding of the structure of proteins and enzymes, the "control" of the cell function by the nucleus is meaningless, etc. In other words, the concept, expected to draw its meaning from what the pupil cannot (meaningfully) know, is bound to remain non-functional.

A long time ago, Carroll (1964), and more recently West and Pines (1984) have stressed the difference between everyday knowledge (intuitive, naive, influenced by language and/or culture) and school knowledge (formal, someone else's interpretation of the world). School knowledge, consisting of complex concepts which are themselves based on complex concepts, has not, in the eyes of the pupils, the same reality as everyday knowledge, and is neither tasted nor tested in the same way by the pupils.

As we have shown above, non-functional knowledge is not only useless, it may be harmful as a generator of erroneous ideas. This is an absurd and absolutely school-made situation: some scientific concepts are so far apart from the world of the pupils that they are unaware of their existence and hence *cannot* form any misconceptions, or make errors, about them -- unless or until someone tries to teach them. If we accept the opinion (of the establishment) that a given concept *must* be taught at a certain age, then we must find a way to establish meanings on the basis of principles which the pupils *can* understand. The implication for the curriculum developer is that "adapting the scientific level of teaching of a concept to the abilities of the pupils" does not mean only the "diluting" of knowledge, i.e presenting only that part of the relevant knowledge which is simple enough to be taught meaningfully at a given age. It means choosing a different approach, designing a specific context, in which the concept can be described by means of meaningful attributes and linked meaningfully to other related concepts.

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APPENDIX

THE IDEA OF THE LIVING CELL, as seen by the "Establishment".

The general idea of the cell, as suggested by the "establishment", was found to be organised, in accordance with the B.S.C.S. approach, under three main headlines: Unity, Diversity and Continuity.

Unity : The cell is the basic unit of life, which means that a)some processes, which are the basic processes of life, take place in all cells; b) a single cell can be self-sufficient and survive i.e, an organism can consist of a single cell.

All cells need energy to survive, are built of protein, produce the energy necessary for their functioning and build their own proteins.

All cells need water, for the biological processes within the cell can take place only in an aqueous medium. All cells have selective membranes. Water penetrates by osmosis.

All cells have a nucleus in which all the information concerning the function of the cell is encoded (often formulated as " which regulates the function of the cell" or "which contains all the hereditary information about the cell"). All cells have some basic features such as a nucleus, membranes, ribosomes, mitochondria etc.; internal structures are adapted to the functions of the cell. Chemical processes in the cell are performed by enzymes.

Diversity : Different cells in multi-celled organisms perform specific functions. Cells "specialise".

The shape and structure of diverse cells vary widely. Different structures are adapted to different functions.

Cells of different structures and functions cooperate within the multicellular organism. Some functions are performed by cooperating cells at different levels of organisation : tissue, organs, organ systems.

Continuity : The origin of every cell is a previous cell. All the information concerning the production of new cells is encoded in the nucleus.

Cells reproduce by division, and this is the process by which an organism ,such as the human body, grows.

When cells divide , all the information encoded in the nucleus must be transmitted to the daughter cells. This information must therefore be duplicated prior to division.

PROMOTING CONCEPTUAL CHANGE IN CLASSROOM SETTINGS: THE EXPERIENCE OF THE CHILDREN'S LEARNING IN SCIENCE PROJECT

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A. INTRODUCTION

Over the last five years the Children's Learning in Science Project, based at the University of Leeds, has undertaken research into the learning of science by 10-15 year old students in classroom settings. The project has been working collaboratively with teachers to develop and evaluate ways of promoting conceptual change in selected topic areas.

This paper outlines features of this research programme and in particular focusses on the strategies which have been adopted to promote conceptual change.

B. THEORETICAL BASES FOR THE RESEARCH PROGRAMME

A number of writers in North America and Europe have referred to the need for a "new conception for science education". The central feature of this "new conception" as far as this project's work is concerned is the premise that knowledge is mind constructed.

This notion underpins several fields of enquiry, each of which informs the project's research on conceptual change in classroom settings (Driver and Oldham 1986; Driver 1986). These fields of enquiry include:

1. Current perspectives in cognitive science in which the learner is seen as an active purposeful constructor of meaning.

2. Contemporary perspectives in philosophy of science in which scientific knowledge itself is seen as a construction of a community of scientists.

3. Interpretive traditions in the social sciences which suggest that individuals' actions depend on the beliefs they hold and the meanings the construe in social situations (including classrooms and schools).

C. IMPLICATIONS FOR SCIENCE EDUCATION

Although these perspectives are by no means novel their implications for science education have not as yet been worked through in practice. In the U.K., for example, classroom practices in science lessons may be broadly characterised as:

1. Didactic: science knowledge is assumed to be objective and absolute; learners are seen as essentially passive recipients of information and any prior knowledge they may have is assumed to be irrelevant. Learning is considered an essentially individual process, the curriculum is seen as that which is to be taught and the teacher is the operator of the 'delivery system'.

2. Discovery: In this approach, which was the one adopted by the major Nuffield sponsored curriculum developments of the 1960s, the knowledge to be learned still tends to be cast as 'objective' but rather than being 'transmitted' by the teacher, it is 'revealed' through the learner's investigations with natural phenomena. Learning is seen as an active process but the prior knowledge of learners is not taken into account. The problems encountered with this style of teaching, of children making 'discoveries' which differ from those intended, have been well documented (Solomon 1980; Wellington 1981) and are attributed to fallacies in the assumptions underlying the pedagogical approach.

3. Process approaches to teaching science are currently gaining prominence in the U.K. Again, children are being cast as active participants in the learning

process. The learning 'goals' are no longer the conceptual schemes of science but the processes by which science is purported to be carried out. In the main such approaches caricature scientific enquiry as an individualistic enterprise based on induction (Millar and Driver 1987).

In contrast with these approaches, this project, along with other research groups, has attempted to take account of current perspectives on cognition and learning, philosophy of science and human behaviour in social settings in order to reformulate the way school is conceptualised and enacted based on constructivist premises.

4. Constructivist approach: In outline this approach is based on a view of the learner as active and purposive in the learning process and involved in bringing prior knowledge to bear in order to construct meanings in new situations. Scientific knowledge is not seen as 'objective' but as socially constructed, a product of human corporate endeavours. If it is the goal of school science that children should understand the scientists' view of the world then this will not be attained through naive approaches of 'asking nature'. Socialisation is an important part of the process.

Fig. 1 here

In this process the curriculum, rather than being considered as 'that which is to be learned', is seen as a set of experiences from which learners construct a view of the world closer to the scientists' view. Figure 1 pictures the curriculum development task from a constructivist perspective. The learner comes to the lessons with prior ideas which need to be taken into account since they influence the meanings that are constructed in the learning situations. There are learning goals - some version of scientists' ideas and ways of thinking. There are also constraints provided by the learning environment in schools, time allocations, material resources as well as more subtle constraints due to teacher's and learner's expectations about knowledge, science, schools and classrooms and their roles in them. During a learning sequence a path has to be traversed by the learners from their present to some future knowledge state. The curricular question is what are the learning activities which enable this to happen effectively?

This question can be answered in part by analysing the domain of knowledge itself. However, since what is learnt from a situation depends both on the situation and on what the learner brings to it in terms of purposes and schemes, the design and selection of learning experiences must ultimately involve empirical investigations of classroom learning.

The teacher's role in such a scenario becomes much more complex than a manager of a 'delivery system'. As a mediator between scientists' knowledge and children's understandings the teacher is required to act as a diagnostician of children's thinking and at the same time to carry a map in his/her head of the conceptual domain which enables appropriate activities to be suggested and meanings negotiated.

D. CURRICULUM DEVELOPMENT AS ACTION RESEARCH

Since teachers are involved in such a fundamental way in the successful implementation of a curriculum, it was decided by this project that the research and development of constructivist approaches to science teaching should be a collaborative exercise between teachers and researchers. Malcolm Skilbeck puts the point very succinctly when he says 'the best place for designing the curriculum is where learners and teachers meet'.

Secondary science teachers from schools within travelling distance of Leeds University were invited to take part in an initial two year project and over 30 teachers undertook the commitment. The purpose of the project was outlined as involving the development of teaching approaches in three topic areas (energy, the structure of matter and plant nutrition*). The teaching approaches were to take account of students' prior ideas and to promote conceptual change. Although the premises on which the project is based were outlined to the participating teachers these were initially construed in various ways by those involved. It is not only the students' prior knowledge which is of concern, 'science teaching depends on the prior knowledge and conceptions of science educators' (Shuell 1986 p.240). This has meant that the project has in effect had two parallel agendas a) the development of teaching schemes which promote conceptual change in secondary school students, and b) the implementation of a way of working as a project which promotes the conceptual development of participating science educators.

Fig. 2 here

Three working groups of about 10 teachers, each with a researcher, were set up, one for each topic area. The programme of work for the two years for each group is represented in Figure 2. The first task each group undertook was to study the learning of the topic in question by students in their own classes (in age range 12-15 years). All participants taught the selected topic in their normal way (this involved a sequence of lessons over six to eight weeks). Students' learning was studied using a number of approaches. Teachers gave their class a diagnostic test before and after teaching the topic and kept a diary while the lessons were progressing. The researcher from the group visited some teachers and kept a more detailed account of the lessons by audiotaping them and interviewing students and the teacher.

The documents which were produced (Bell and Brook 1985; Brook and Driver 1986; Wightman 1986) were used as a basis for reflection on current practice by the group. Students' particular conceptual problems were documented and pedagogical concerns were also identified. At this stage, the groups were attempting to make explicit their views on the scientific ideas to be taught and to share their developing perspectives on the teaching and learning processes.

Towards the end of the first year each group worked together for a week to devise a revised teaching scheme for their topic, drawing on the insights gained over the year and further reading of the research literature. All the schemes were designed to take account of students' prior ideas in the topic and to provide learning activities and a learning environment aimed at promoting conceptual change. (General features of the strategies adopted are given in the next section.)

The revised schemes were implemented in the second year of work and the learning taking place in the classrooms was monitored again in the same way. The groups met for a weekend to review the findings from the first trial of the schemes. Undoubtedly these first trials led to a greater understanding of some of the students' conceptual problems. It also gave insight into reactions by teachers in implementing a much more open approach in their classrooms. As a result of this phase, revisions were made to the schemes which were retrialled prior to publication.

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* These are topic areas in which the project had already undertaken research on children's thinking and which presented conceptual problems.

E. CONCEPTIONS AND CONCEPTUAL CHANGE

Before considering the issue of conceptual change it may be useful to review briefly the characteristics of students' prior conceptions. Many techniques to investigate students' ideas use verbal methods of elicitation and it is easy to overlook the fact that much of the knowledge we all have about the natural world is not language based. We release a ball from our hand and we anticipate the direction it will go, the time it will take to fall; we hold a hand between our eyes and a light source anticipating our eyes will no longer be affected by the glare; we throw a stone into a pond and can anticipate the noise made, the ripples that will be produced, the sinking of the stone. These examples of structured knowledge of phenomena in which perceptual images are linked in time and space I will call phenomenological schemes. Two further points about these schemes should be noted. They may become quite complex as in the case of a child playing with shadows of an object cast by a light source. In this case the child may construct a scheme which appropriately represents the relative positions of the light source, object and shadow and may also construct a scheme enabling it to predict what happens to the size of the shadow as the light source is moved towards or away from the object. The second point to note is that people may use such schemes without making them explicit to themselves or others through language or other symbolic forms.

Communication about these phenomenological schemes may be mediated symbolically e.g. through language. In which case I will refer to them as conceptions. I prefer not to use the term 'propositional knowledge' since students may have symbolic or language structures without these necessarily relating to phenomenological experience (e.g. instances of rote learning from simple phrases such as 'energy is neither created nor destroyed' to complex symbolic systems such as sets of equations in kinematics, optics or chemical energetics). A conception from this point of view, therefore, implies structured knowledge of a class of phenomena represented in some symbolic form.

It follows that in order to change a person's conception, involves either changes in their phenomenological schemes or their symbolic representation of these schemes or both.

How more complex conceptual structures are developed from simpler ones is a question which psychologists and science educators are only beginning to tackle (despite the fact that learning of this kind occurs daily in classrooms!). Students - at least some of them - do develop a working understanding of Newtonian mechanics, electrical circuits, genetics, as a result of school teaching.

In attempting to understand how more complex conceptual schemes develop from simpler ones, various underlying hypotheses concerning conceptual change require examination.

Information processing models of cognitive functioning may account for a range of aspects of students' performances in science tasks. However, the computational model by itself falls short in accounting for conceptual change involving the restructuring of schemes.

Such models tend to focus on propositional knowledge without representing the phenomenological schemes and the connections between these and symbolic systems. It also sheds little light on the critical problems of how interfacing occurs. How is it, for example, that two physics students may both have symbolic knowledge schemes concerned with, say, the conservation of momentum. Yet in a practical situation one, not the other, brings this scheme into operation?

Social transmission has been put forward as a mechanism to account for and to promote the development of more complex conceptions, and certainly needs to be taken into account in considering the structuring of learning environments. However, ultimately the question has to be faced as to how the more complex processes which may have been imitated or through which a learner may have been guided, become internalised; how does the process of personal construction and representation of conceptions take place?

It is an answer to this questions which is needed in order to develop a more soundly based pedagogy.

F. STRATEGIES FOR PROMOTING CONCEPTUAL CHANGE IN CLASSROOM SETTINGS

Some general principles

In developing schemes of work designed to promote conceptual change, a number of general principles were used by the project in setting up an appropriate learning environment:

1. General structure of schemes

All the schemes follow the same general pattern for a sequence of six to twelve lessons. This is shown in Figure 3. After a scene setting orientation activity in which students' attention and interest in the topic is aroused, the class spends time discussing and reviewing their own ideas or models. This elicitation phase is usually conducted in small groups first. Each group is asked to represent their ideas on a poster or by other means and then present these to the class as a whole. Similarities and differences in students' prior ideas are identified and issues for further consideration are noted. The posters remain displayed as a record during the rest of the unit of work and may later be amended or commented on.

Fig. 3 here

The restructuring phase, the heart of the scheme, has involved the use of a wide range of strategies which are reviewed in the next section.

The lesson sequence then gives students opportunities to try out and apply their revised conceptions in a range of ways. This may involve practical construction tasks, imaginative writing tasks or more conventional text book problems to solve.

At the end of the lesson sequence classes are given the opportunity to review the extent and ways in which their thinking has changed. The earlier posters may be modified or new ones constructed and compared with the earlier ones.

2. The context of learning tasks

As far as possible the learning tasks were chosen to be memorable (surprising, amusing) or to be set in contexts which were meaningful to students (e.g. some of the work on energy was set in domestic contexts and involved reading meters, using fuel bills). We know that knowledge is contextually embedded. If schemes are to be developed, the context in which this is done may be important in maintaining attention and facilitating later applicability of the conceptions.

3. Non-threatening learning environment

A learning environment which requires students to make their ideas explicit and to test out new ways of thinking could be very threatening. If students' efforts are evaluated too early by the teacher or by other students then they will tend not to experiment but want to be told thus possibly short-circuiting the knowledge construction process.

Setting up this non-threatening environment in classes has been attempted by developing strategies to enable students to express their ideas in an organised way through group work, poster displays etc. It has also required teachers in many cases to change their class discussion management routines quite radically, avoiding closed questions, accepting a range of suggestions from a class without requiring premature closure on a point.

4. Small group work

The importance of talk in enabling learners to represent their ideas to themselves has been recognised for years. Small groups of about four students form the structural unit around which the scheme of activities takes place. Group activities involve discussing and representing theories or ideas on a topic, devising experiments to test their ideas, developing more complex models to represent experiences, undertaking practical construction tasks in which conceptions are applied.

5. Metacognition

This term is used here to describe the process whereby students reflect on their own knowledge and how it is changing. Students tend to think of learning science as 'taking in' discrete facts. Strategies which encourage students to reflect on their own learning helps them appreciate that a process of conceptual change is involved, also that their knowledge is structured and interrelated. Techniques which we have used to encourage this process include students comparing their ideas at the beginning and end of a learning sequence also keeping personal learning logs (small notebooks in which they record their reactions to lessons, notes on what they think, things they find difficult etc.).

G. MANOEUVRES FOR PROMOTING CONCEPTUAL CHANGE

This section outlines the various manoeuvres which have been used in the experimental teaching to promote restructuring of students' conceptions. It is not intended as an exhaustive list nor as a complete analysis of the range of possible manoeuvres.

The use of counter evidence in promoting conceptual change has received considerable attention. Here, however, it is suggested that it does not address the heart of the problem. First let us schematise the process of conceptual change. Figure 4 gives a simplified representation in which a student's initial conception (C_1) assimilates a range of experiences (E_1-E_n). As various people have indicated, the introduction of a counter example (E_{n+1}) which cannot be assimilated by C_1 may result in a number of outcomes (e.g. the experience itself may be discounted, special conditions may be invoked to account for it etc.). By itself the counter example does not generate a new conception C_2. For conceptual change to take place first a new conception has to be constructed and the range of experiences which had previously been accounted for have to be reassimilated to that new conception. Counter evidence by itself is clearly not sufficient to promote change.

Fig. 4 here

In order to encourage the construction of new conceptions a number of different teaching manoeuvres have been used within the project's schemes depending on the nature of the students' prior conceptions and the learning goals:

1. Broadening the range of application of a conception:
   Students' prior conceptions may be a resource which can be extended. For example, for younger children energy is attributed to human energeticness and motion. By inviting children to consider what happens to their energy, the notion can be generalised to encompass the motion of inanimate objects leading on to an appreciation of energy being stored in springs etc.

2. Differentiation of a conception:
   In many areas students' conceptions can be global and ill defined and particular experiences are necessary to help them differentiate their notions (e.g. heat and temperature, force and energy, weight and moment). (In some cases students do have differentiated phenomenological schemes but do not have the symbolic referents. In this case the problem is trivial.)

   In the area of energy, we found that students were often unable to differentiate between the weight of an object (the force of the Earth's gravitational field on the object which within normal human experience is constant with changes in height above the Earth's surface) and the energy transferred when the object is lifted up. Due to this confusion, students would assert that an object gained weight on being lifted up yet this was not supported by the evidence of spring balance readings. There was a need for a 'something' that changed while 'something else' remained constant.

3. Building experiential bridges to a new conception:
   Research by Brown and Clement (1987) with college students has indicated the importance of thought experiments in constructing conceptual bridges. Our work has been with younger students and perhaps not surprisingly we find it can be important for such bridges to be constructed through practical experiences.

   A prior conception about energy which is widely held is that energy can disappear. In the case of a hot cup of tea in a room, students assert that the tea cools down and the heat energy disappears. To encourage them to construct the notion that energy does not disappear but that it goes somewhere, possibly 'spreading out' so it is less detectable, the class conducted a series of experiments in which a hot cup of water was allowed to cool in outer containters of cold water of progressively larger volumes. The temperature of the water in the inner and outer containers was recorded and plotted at regular intervals of time. After inspecting the resulting graphs, students were then asked to think about what happens when he outer container is the room itself. Having done the activity and plotted the graphs, students were able to construct in their imagination the notion of heat being 'spread out' in the room.

4. Unpacking a conceptual problem:
   In some cases a conceptual problem occurs which cannot be solved directly but requires a deeper problem to be addressed. A clear example of this occurs in the teaching of the kinetic-molecular theory of gases where children will accept the existence of particles but have difficulty with the notion of intrinsic motion. The prior conception to be dealt with here is the well known conception of 'motion requiring a force'.

   An analysis of learning problems of this kind could give some guidance to the sequencing of topics in curriculum as a whole.

5. The importing of a different model or analogy:
   In the lessons on the structure of matter, students were asked to examine the properties of a range of substances and account for them. The observation that a gas is 'squashy' elicited ideas among some students that gases are not continuous stuff but made of particles with spaces between them. Simple experiences with objects in one domain are being drawn on to account for behaviour in another domain.

   It is probable that early experiences provide children with a series of phenomenological schemes which are important for them to draw on in later science teaching. Such schemes could include flow in both open and closed systems, spreading out and packing together of entities, oscillating systems, systems where action is dissipated (e.g. fuel burns up, an object is pushed, object moves until the push is used up).

6. The progressive shaping of a conception:
   In the teaching of the particle theory of matter we find the initial idea that matter is particulate rather than continuous is rapidly adopted by 12 year old pupils. The properties of those particles and the way their behaviour accounts for various macroscopic properties has to be treated progressively as students come to explore the range and limitations of their theories. Experiences which focus attention on intrinsic motion of particles and the forces between particles have been found to be important. In adopting a model, students need opportunities to test it out, see where it fails in order to adapt it. Some bits will be constructed which conform to scientific ideas, others will not (e.g. the that particles expand on heating or that there is air between particles are commonly used).

7. The construction of an alternative conception:
   In some cases students' prior ideas are incommensurate with the scientific conceptions. In a case of this kind we have acknowledged students' prior ideas and discussed them, then indicated that scientists have a different view. An alternative model is built up drawing on other prior ideas.

   This was the approach we took to teaching plant nutrition. Students prior ideas about plant nutrition focussed on the notion of food as something taken in from outside the plant. Within this conception water, and 'goodness from the soil' even light, are seen as food for plants. The scientific notion, however, hinges on an alternative conception for food - that of a supply of energy for maintaining the processes of a living system. In the case of green plants, food is synthesised.

   The discontinuity in the students' basic conception and that of scientists was recognised in the teaching and an alternative conceptual scheme for plant nutrition was presented together with practical experiences supporting it.

In this task of designing, trialling and evaluating teaching sequences which are better tuned to learners' understanding it has been necessary to consider the nature of learners' conceptions and how they differ from the learning goals in order to identify appropriate pedagogical manoeuvres. This leads us to comment that strategies for promoting conceptual change need to be investigated in the context of particular domains of knowledge. General prescriptions of the conceptual change process by itself is not enough. Information about the nature of the conceptual change to be promoted is necessary in designing instructional sequences.

The main outcomes of this phase of the programme have been ethnographic accounts of the learning taking place in classrooms in which each of the three topics have been studied. The paths in students' thinking have been documented together with the manoeuvres teachers have used to promote conceptual change.

A major feature which has emerged from these accounts and the feedback from working groups is the extent to which similiar ideas and difficulties occurred in the classrooms of different teachers. In other words, there is evidence that there is commonality in the learning path followed by different classes of students. If this is the case then such information can be shared with other science teachers. The schemes have therefore been written up for publication in a way which not only outlines the methods of organising the classroom and the activities recommended, but which aims to give some insight into the conceptual progress which students make during the scheme of work.

H. ONGOING CONCERNS

The project has a number of ongoing concerns including:

1. We know that in the short term students' attitudes to their learning is enhanced by these methods, that they become more aware of their own learning processes and gain some insight into the scientific enterprise. What, however, is the effect on students' learning in science in the longer term of adopting these strategies?

2. The work over the last few years has indicated the magnitude of the changes in teachers' views and practices which are demanded by these ways of working. The project is currently focussing attention on the development of in-service materials for science teachers in order to encourage them to think through their views of learning and to encourage changes in classroom practice.

3. The sequencing of topics in the science curriculum, in a way which takes account of the progressive development of students' conceptions, is also a matter which the project is addressing.

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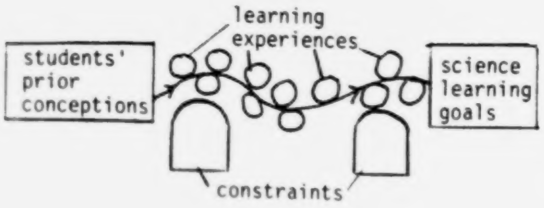
learning experiences
students' prior conceptions
science learning goals
constraints

Fig. 1 A picture of the curriculum development task from a constructivist perspective

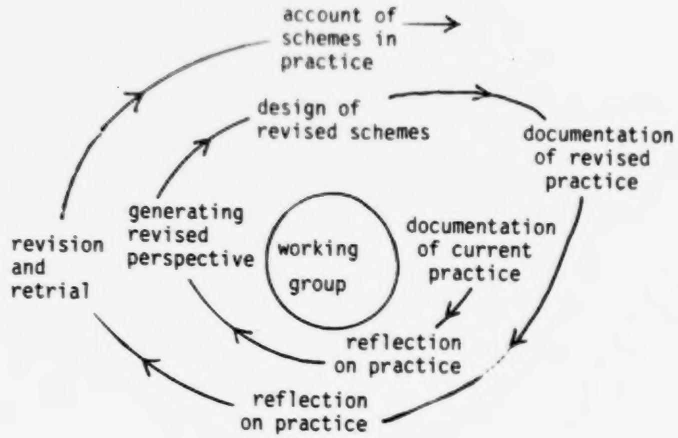
account of schemes in practice
design of revised schemes
documentation of revised practice
generating revised perspective
working group
documentation of current practice
revision and retrial
reflection on practice
reflection on practice

Fig. 2 The programme of working groups

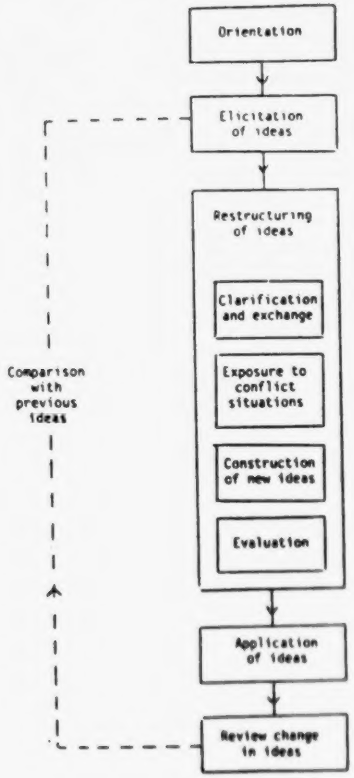
Orientation
Elicitation of ideas
Restructuring of ideas
Clarification and exchange
Exposure to conflict situations
Construction of new ideas
Evaluation
Application of ideas
Review change in ideas
Comparison with previous ideas

Fig. 3 General structure to teaching sequence

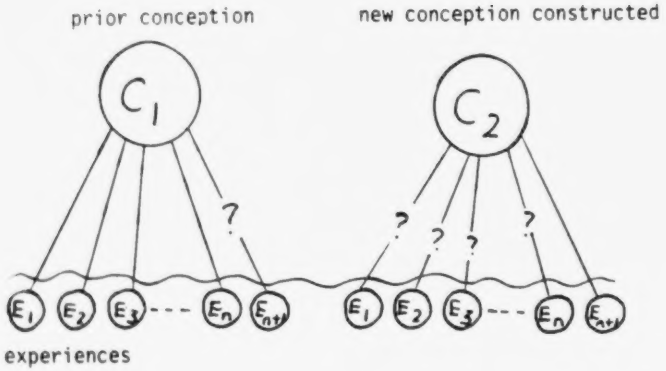
prior conception
new conception constructed
C_1
C_2
?
? ? ? ?
E_1 E_2 E_3 --- E_n E_{n+1}
E_1 E_2 E_3 --- E_n E_{n+1}
experiences

Fig. 4 A representation of conceptual change

A COMPARISON OF TEACHER-STUDENT CONCEPTIONS IN OPTICS

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INTRODUCTION

Most creative and conscientious teachers spend a considerable amount of time and effort designing presentations, activities and demonstrations that will enhance the learning process. As part of this process, the teaching practitioners look for explicit ways to deal with their students' preconceptions and misconceptions and to help them overcome their conceptual difficulties. This task becomes compounded for those of us who teach prospective teachers. For we suspect that, more often than not, the teacher-to-be shares some of the preconceptions of the children s\he will teach.

The clearest way of ascertaining whether teacher and child share a preconception is to do similar research with both. The present work carries out this comparison in reference to some notions in the field of optics, by extending some of the work we have done with school children (ages 9 to 13) into the teacher-training college classroom. (See Rice and Feher, 1987; Feher and Rice, 1987.)

FORMATION OF IMAGES AND SHADOWS

Studies of the conceptual difficulties of college students in the field of optics have been based mostly on tasks that involve reflection from mirrors and refraction through lenses (Goldberg and McDermott, 1987). A wider spectrum of questions and methodologies has been used with children to elicit their notions about phenomena involving light (Guesne, 1985; Feher and Rice, 1985; Andersson and Karrqvist, 1983; Jung, 1982, 1981a, 1981b; Stead and Osborne, 1980; Hawkins, 1978). However, tasks with mirrors and lenses remain favorites

The questions that we have asked both children and teachers center around effects that give much information on the observer's ideas about light propagation without involving concepts of reflection and refraction. The set-up to produce these effects consists of a screen, a light source in the shape of a cross, and objects that are placed about halfway between source and screen. The objects provide windows for the light to go through and form images, or they are obstacles that block the passage of light and form shadows on the screen.

The basic effect is that a very small hole (small in comparison with the size of the source) produces an image on the screen that is in the shape of the light source, a cross. This is the principle of the pinhole camera. The standard explanation is in terms of a ray diagram that shows a point by point correspondence between the source and the image (Fig.1). Using a very small bead, a shadow in the shape of a cross appears on the screen. This is very surprising to almost all observers. When a large round window or a large round ball are used, the image and shadow respectively produced are approximately circular. The latter effects are more common in our every day experience since we usually deal with objects that are large with respect to the source or very close to the screen. In Fig. 1 we summarize these four effects in a manner that emphasizes the symmetry between the images and the shadows. In fact, if one understands how the images are formed, the shadows can be thought of as anti-images: they occur where the images are blocked.

In our work with children we did not find evidence of this conceptual symmetry between shadows and images. Shadows often are conceived not as absence of light but, rather, as another kind of image, one that has concrete existence and object-like characteristics and that we have termed a *reified* shadow. This reified shadow often appears in a two-step model of shadow formation that we call the *trigger* model in which the light acts upon the object, provokes it, as it were, to cast its shadow.

Another interesting result of our work with children is the *holistic* notion that light propagates as a whole in the shape of the source (in our case, a cross) in a preferential direction. In the *fit* model, the images and shadows are constructed by using parallel rays to determine how much of the shape of the source fits through a window or is blocked by an obstacle. In the *squeeze* model, the images are constructed by funneling the whole shape of the source through the window (Fig.2). A fundamental concept that is conspicuously missing in these ideas is that each element of the source emits light rays in all directions.

The purpose of our work with teachers was to determine if in their ways of thinking we could find traces of the notions held by children.

PROCEDURES AND RESULTS

The subjects in this work were sixty-two pre-service elementary school teachers who were enrolled in two sections of a required one-semester, upper division science course. Aside from a methods course, these students will receive no further training in science before they are certified as teachers. One of us, using simple portable equipment (see description in Feher and Rice, 1986) in front of each class, asked the students for written predictions, including explanatory diagrams, of the effects we have previously discussed. The students were then shown the actual effects and asked for written explanations.

The protocol we used (Table I) is based on the ones developed for our previous work with children. There is, however, a fundamental difference: The children were individually interviewed at the site of an interactive exhibit in a science museum, whereas the college students were asked collectively for written responses to questions about phenomena demonstrated in a classroom. We feel very strongly that the use of written responses in this work yields meaningful results only because we are building upon the background and information afforded by the hundreds of detailed interviews previously held with children.

To analyze the data, we organized the questions and answers in a matrix format (see illustration in Fig.3) with the questions from the protocol along the top horizontal line and the data from one interview in each row below it. This method of organization permits comparison of the answers of different subjects to the same question and also allows us to follow the answers of one subject to the different questions.

In the results that follow we treat the two class sections as one homogeneous group since there were no significant differences in the answers obtained from the two sets of students. However, at the time that we questioned them, the two classes had covered different subject matter and one class had spent about 20 hours on hands-on geometric optics while the other class had not studied the subject.

Predictions for apertures. The adult students' predictions follow the same general pattern as the children's (Table II). Almost all of the students predict (incorrectly) a circular image for the small hole; as the size of the hole increases, more students predict they will see a cross (or a shape that is a blend of a cross and a circle) and almost one half the class predicts a cross when there is nothing placed between source and screen (a situation equivalent to a hole of infinite size). The latter prediction is particularly interesting because it seems to contradict the often-used argument that students' naive ideas are based on common experiences. After all, fluorescent tubes are fairly common, and they do not form linear images.

Most of the students that drew complete diagrams for each prediction (many students did not) showed parallel rays from the source that span the size of the hole and go to the screen.

A noteworthy subset of the students is the quarter of the sample that predicted different images for the big and the small hole: a cross or a blend (a cross with a circle) for the large hole and a small circle for the small hole. These predictions are the precise opposite of what

actually happens. The predictions are made using the geometrical construction that we call the fit model: all the parallel rays emitted by the source fit through the large hole and arrive at the screen in the shape of the cross light. In the case of the small hole, only the rays emitted by a minute portion of the cross arrive at the screen, creating a dot or small circle. Verbal explanations state that: "The two images are different because there is not enough space in the pinhole to shine the entire cross through." (See Fig. 3, first three columns).

What is a shadow? The adult students answered this question by describing how a shadow is formed (See Table III). The majority of them attribute the shadow to the absence of light. The remainder describe a two step process involving a dynamic light, an active object and a reified shadow. One-quarter of the students used language similar to that of the children, calling the shadow an "image" of the object.

Predictions for obstacles. The majority of the adult students, like the children, predicted that the shadow would be in the shape of the object, a circle for both the ball and the bead. (See Table IV.) Of the students who explained their predictions, two-thirds attribute the shadow to an absence of light, either because the light is blocked by the object or because it is deflected by the object: "The ball will block the light leaving a blank spot on the screen", "The light rays will pass around the ball creating a shadow on the screen." Some of the remaining answers attribute the shadow on the screen primarily to the action of the object: "The bead will create a small shadow."; "The softball reflects its shape on the screen."

The rest use the verb in the passive voice without attributing the action to a specific subject: "A shadow a little bigger than the actual bead will be projected to the screen." (See Table V.)

The diagrams that accompany the shadow predictions, like those used for apertures, show mostly parallel rays from the source spanning the size of the object and going to the screen. In these diagrams it is often difficult to distinguish which areas are lit and which are dark. This is a problem due to the metholdology; in the work with children questions of this type could be clarified during the interview.

Explanations after seeing the effects. Many of the students were dismayed when they saw the pinhole effect and one-third of them said they had no idea why the image was a cross. We classified the explanations given into four types:

1. those that state it is because the light is a cross and give no further explanation.
2. those that focus on an active role of the hole. The hole "restricts," "filters," "isolates" the light.
3. those that refer to the way that light travels, "The rays of light are coming out of the filament as vertical and horizontal lines and continue on their path as one."
4. those that use passive verbiage indicating that the light is acted upon but do not say by what: "The light is funneled through the pinhole."

See Table VI for examples and frequency distribution.

Half the students did not attempt an explanation of the cross-shaped shadow of the bead. Of those that did explain, one-quarter said the cross on the screen is an image or shadow of the source; "The object is small enough that it allows the light source to produce a shadow."; "The light source is reflected off the bead." A few students insisted that the shadow of the bead was in the center of the cross-shaped shadow: "The bead is inside the shadow of the cross." Many of the remaining students claimed that the effect was due to the object: "Smaller objects seem to filter and concentrate the source." These answers are of the same type as the majority of the children's explanations. (See Table VII)

DISCUSSION

What are the outstanding features of the teachers' responses and how do they compare to children's?

The holistic concept of light propagation. A considerable proportion of the teachers think that light propagates as a whole, in the shape of the source and in the direction of the screen. This conception and the diagrams with parallel rays that usually accompany it are described also by Goldberg and McDermott in their work with lenses (1987). Our work indicates that this way of thinking is not limited to students using ray diagrams to explain refractive phenomena. It is a deeply ingrained notion used by adults and children alike to describe the propagation of light in free space.

The "fit" model. In the Results section we noted that a group of students used the fit model to predict the shape and size of the images. The group is easily identifiable because the shapes predicted are the precise opposite of the actual effect. When we followed the answers of these students through to see how they arrived at their predictions for shadows, we found that one half of them continued to use the fit model all the way. Examples from this subset are shown in Figure 3. These students, thirteen percent of our sample, used a reasonably well-defined, geometric model that incorporates some correct notions (shadows are absence of light) and some incorrect ones (each element of the source emits one ray, or, the image of the source travels parallel to itself). Most important, they used this model consistently, attempting to treat images and shadows as if they were, indeed, counterparts of each other.

The "squeeze" model. This model, in which the cross light travels as a whole entity towards the small hole, squeezes through and spreads out on the other side, was used amply by the children both in their predictions and in their explanations. The prospective teachers, however, did not use the idea of squeeze in their predictions. They only resorted to it in order to explain the mystifying cross-shapes, seemingly falling back on more naive ideas to resolve the challenge.

The "trigger" model. An unexpectedly large proportion of the pre-service teachers did not invoke the blocking of rays of light to explain shadows. These students used a two step explanation of shadow formation that is similar to that used by the majority of the children: The light, upon hitting the opaque object, initiates or triggers the movement of the shadow to the screen. The language of the adults is less dramatic than the children's. For example, the shadow is "cast" or "projected" rather than "thrown forward" by the object. And whereas many of the children said the light pushes the shadow to the screen, none of the adults said so. But, the basic elements of the

trigger model are clearly discernible in the responses of these adults that describe the shadow as the presence of something rather than the absence of light.

Language. In the absence of a geometric construction that allows them to predict or explain correctly, the prospective teachers and the children alike resort to action verbs. So, for example, to produce a cross image, "the hole concentrates" the light. Adult students that presumably felt this verbiage rendered the role of the hole too magical, said "the light is concentrated". This use of the passive voice that leaves the subject of the action unspecified is totally absent in the children's explanations. The children use the active form and, moreover, active reflexives, where the subject acts on itself: "The light gets itself smaller and goes through the hole". The adult use of the passive voice serves to obscure what is not understood.

CONCLUSIONS

The tasks we posed for the students in this research amount to problem solving at a qualitative level. The intellectual baggage that the teachers brought to bear to this problem solving was similar to that of the children. The difference was mostly a matter of degree: the proportion of adults that used some correct concepts was larger, but whereas the children expressed their ideas very directly, the adults' use of language (e.g.the passive voice) often masked their lack of understanding. So, although sometimes in a subtle form more difficult to detect, most of the primitive conceptions held by the children were also found in the adults' responses.

This problem solving approach, with unfamiliar phenomena, that we have used for the research provides a powerful way of engaging class interest, of piquing student curiosity and of uncovering students' convictions.At the end of our questioning sessions, the majority of the students in the class stayed behind, intrigued with what they had seen, wanting to discuss the models and mechanisms that explain the effects correctly. Thus the research technique, with slight variations in interpretation, becomes a powerful instructional strategy. Broken down into its four steps, our prescription for teaching is: to *elicit*, to *confront*, to *engage*, to *extend.*

We elicit the preconceptions of the students by asking for their predictions. This fulfils a diagnostic role since, from the results of research, we know which are the common preconceptions. For exmple in the present work with the teachers the fit model gives a very characteristic set of predictions that tell us how the student is thinking, with a fair degree of certainty and without recourse to elaborate interviewing.

From the standpoint of the student, predicting amounts to making a bet on the outcome of the task. It is a commitment that gives each student the opportunity of being right and feeling successful, or of being wrong and wondering why. There is an important affective component in this commitment.

The confrontation with the dramatic outcome acts as a powerful motivator for the student to give explanations and engage intellectually in the problem. The phenomenon experienced is assimilated

and/or the mental structures shifted to accommodate the discrepant event.

The fourth step is to expose the students to other conceptually similar phenomena; this serves the purpose of extending and internalizing their experience.

We have described a strategy for teaching that is of very general applicability. It is particularly important when dealing with teachers who, if they are not aware of their preconceptions, are in a position to reinforce similar unscientific thinking on the part of their students. By confronting the future teachers with their own naive conceptions we are teaching by example how to deal with this problem and giving them the tools so that they, in turn, can foster their own students' learning in a similar fashion.

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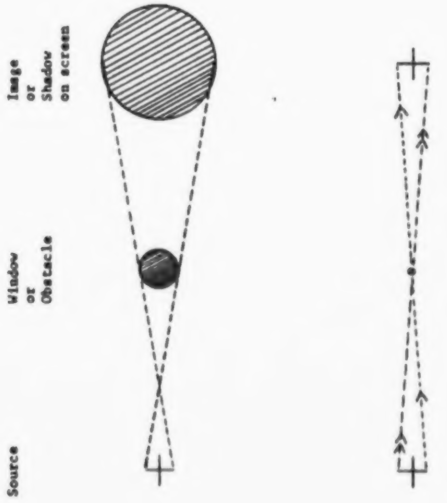
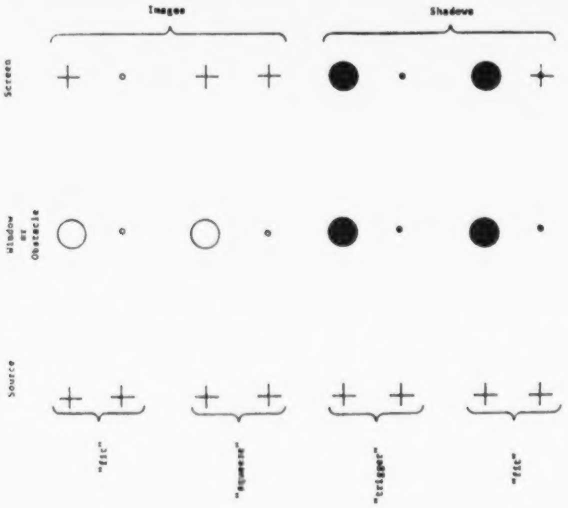


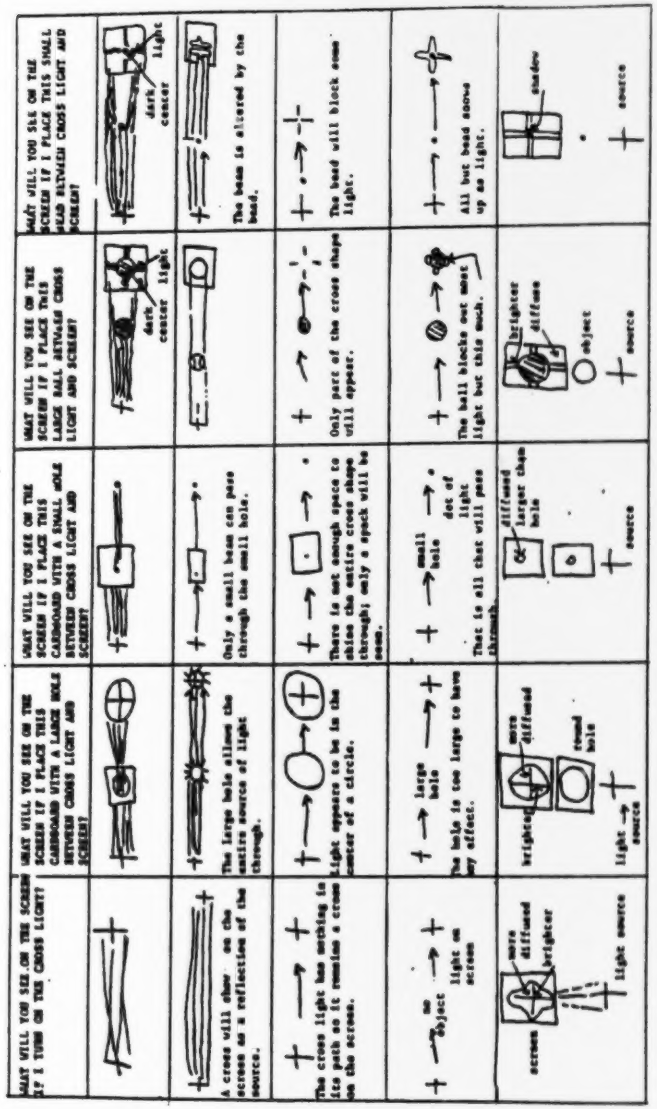
Source
Window or Obstacle
Image or Shadow on screen

FIGURE 1. Schematic of the four effects. The dotted lines are limiting light rays that determine the size of the image or shadow on the screen.



Images
Shadows
Screen
Window or Obstacle
Source
"fit"
"squeeze"
"trigger"
"fit"

FIGURE 2. Predictions obtained with different models.



WHAT WILL YOU SEE ON THE SCREEN IF I TURN ON THE CROSS LIGHT?

A cross will show on the screen as a reflection of the source.

The cross light has nothing in its path so it remains a cross on the screen.

WHAT WILL YOU SEE ON THE SCREEN IF I PLACE THIS CARDBOARD WITH A LARGE HOLE BETWEEN CROSS LIGHT AND SCREEN?

The large hole allows the entire source of light through.

Light appears to be in the center of a circle.

The hole is too large to have any affect.

WHAT WILL YOU SEE ON THE SCREEN IF I PLACE THIS CARDBOARD WITH A SMALL HOLE BETWEEN CROSS LIGHT AND SCREEN?

Only a small beam can pass through the small hole.

There is not enough space to shine the entire cross shape through; only a speck will be seen.

That is all that will pass through.

WHAT WILL YOU SEE ON THE SCREEN IF I PLACE THIS LARGE BALL BETWEEN CROSS LIGHT AND SCREEN?

Only part of the cross shape will appear.

The ball blocks out most light but this much.

WHAT WILL YOU SEE ON THE SCREEN IF I PLACE THIS SMALL BEAD BETWEEN CROSS LIGHT AND SCREEN?

The beam is altered by the bead.

The bead will block some light.

All but bead shows up as light.

no object
light on screen
screen
more diffused
brighter
light source
large hole
more diffused
round hole
brighter
light → source
small hole
dot of light
diffused larger than hole
source
dark center
light
brighter
diffuse
object
source
dark center
light
shadow
source

FIGURE 3. Portion of the matrix illustrating the answers of students that used the "fit" model consistently.

TABLE I
Protocol used with pre-service teachers.

1. "What will you see on the screen if I turn on the cross light? Can you draw what happens?"

2. "What will you see on the screen if I turn on the light source and I place this cardboard with a large round hole here (halfway between the cross light and screen)? Can you draw what happens?"

3. "What will you see on the screen if I turn on the light source and I place this cardboard with a small round hole here (halfway between the cross light and screen)? Can you draw what happens?"

4. "What is a shadow?"

5. "What will you see on the screen if I turn on the light source and I place this large ball here (halfway between the cross light and screen)? Can you draw what happens?"

6. "What will you see on the screen if I turn on the light source and I place this small bead here (halfway between the cross light and screen)? Can you draw what happens?"

7. Interviewer turns on the light while holding object with small hole and then object with large hole halfway between light source and screen. "How can you explain the images that you have just seen?"

8. Interviewer turns on the light while holding the small bead and then the large ball halfway between light source and screen. "How can you explain the shadows that you have just seen?"

TABLE II
Predictions of the shape of the image by adults and children.
The asterisks indicate correct responses.

	SIZE OF APERTURE	PREDICTED IMAGE ○	+	Blended shapes e.g. ⊕ ⌖	NUMBER OF SUBJECTS
Adult	infinite	*57%	43%	N/A	62
	large	*72%	12%	16%	60
	small	97%	*3%	0	58
Child	infinite	*50%	50%	N/A	22
	large	*54%	22%	24%	41
	small	80%	*15%	5%	41

TABLE III
"What is a shadow?": Frequencies of various types of answers.

	TYPE	EXAMPLE	FREQUENCY Adult N=30	FREQUENCY Child N=40
A shadow is formed when	Light is blocked or deflected	"The absence of light formed when light is blocked from illuminating a surface." "An image that is formed when light is blocked by an object."	73%	27%
	Light acts on object	"A shadow is an image projected from an object when light is shining on it." "When light hits an object,the object reflects the shadow."	17%	45%
A shadow is a	Reflection or image	"It's a reflection of yourself." "It's like a picture of yourself with no color."	-	28%
	Miscellaneous		10%	-

TABLE IV
Predictions of the shape of the shadow by adults and children.
The asterisks indicate correct responses.

	SIZE OF OBSTABLES	PREDICTED SHADOWS ●	+	Blended shapes e.g. ● ✦	NUMBER OF SUBJECTS
Adult	large	*86%	-	14%	57
	small	81%	*6%	13%	47
Child	large	*78%	2%	20%	40
	small	78%	*-	22%	40

TABLE V
Explanations that accompany the shadow predictions.

	TYPE	EXAMPLE	FREQUENCY Adult N=54	FREQUENCY Child N=40
Absence of light	Light is blocked	"A dark area will appear where the ball is blocking light."	50%	20%
	Light is deflected	"The light rays will flow around the ball and light the whole screen except for a small shadow."	17%	7%
Reified shadow	Object casts shadow	"The ball will reflect light and cast a shadow on the screen."	22%	26%
	Light pushes shadow	"Light pushes the shadow like a wave pushes a ball in water."	-	47%
	Passive voice	"A shadow will be cast on the screen."	11%	-

TABLE VI
"Why is the image a cross?: Explanations and frequency distribution

TYPE	EXAMPLE	FREQUENCY Adult N=62	 Child N=50
Restatement	"These two lines join to form a cross."	15%	26%
Active hole	"The small hole is isolating the light source." The small hole seems to filter the light into its original position of a cross." "The hole limits the light so it is more concentrated and maintains the cross shape."	11%	20%
Active light	"Light travels in the way it is given off." "The light is shaped like a cross; when it goes through the hole, it will still be in its original shape."	29%	40%
Passive voice (light is acted upon)	"The light is channeled through the hole." "The light is filtered through the pinhole." "The light is compressed and gives the same effect as viewing an eclipse through cardboard." "The shape of the source is filtered through the small hole and reduced."	13%	0
Miscellaneous		32%	14%

TABLE VII
"Why is the shadow a cross?": Explanations and frequency distribution.

TYPE	EXAMPLE	FREQUENCY Adult N=30	 Child N=40
No answer	---	50%	-
Shadow of source	"The object was small enough that it allows the light source to produce a shadow." "It's the shadow of the light."	25%	75%
Miscellaneous		25%	25%

Changes in Students' Knowledge During A Simulated Search for Oil

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Problem

There have been many claims that having students solve relatively complex problems is instructive --- that is, that the students' learn a great deal of new information in the process. Unfortunately, there has been little empirical research to support that claim. One type of problem that can be studied are computer simulations of domain specific problems. There have been many of these developed for use in instruction and they offer an opportunity to study exactly what changes in students' knowledge actually occur when problem solving is used as an instructional technique. The study reported here is a determination of the changes in students' knowledge that result from their attempts to solve a simulated geological problem. The results inform instructional designers as to the value of problem solving simulations and researchers as to what knowledge changes occur as a result of their use.

Rationale

The rationale for the study is based on recent theoretical and empirical research in cognitive psychology, specifically schema theory (Anderson, 1980; Lindsay and Norman, 1977; Rumelhart, 1980) and problem solving (Larkin and Reif, 1979; Newell and Simon, 1972; Tuma and Reif, 1980), as well as the science education research in conceptual change (Driver and Erickson, 1983; Posner, Strike, Hewson, and Gertzog, 1982). That research provided the following ideas that were used to to develop this study:

(1) describing what students learn is a matter of determining the changes in prior knowledge that result from instruction. The emphasis on changes in knowledge is based on clear evidence that new knowledge is the result of the interaction of prior knowledge with instructional content;

(2) There are two integrated components of the students' knowledge. One is the conceptual knowledge --- the propositions used as the problem solving occurs. The other is procedural knowledge --- the sequence of goals and actions that occur as the problem is solved.

(3) Students' knowledge can be represented in a way that captures both the conceptual and procedural knowledge in terms of the goals they establish, the reasons the goals were established, the actions taken to meet those goals, the reasons for those actions, and the conclusions made based on the information obtained from each action.

Method

Subjects

Since one of the major tenets of the study was that prior knowledge is a major determinant of what is learned from instruction, an attempt was made to use students with widely varying backgrounds. Four students were selected. One student had an extensive background in chemistry but no

course work in geology (Wendy). The second student had a minimal background consisting of one physical geology course, one historical geology course and one environmental geology course (Mary). The third had completed a geology degree but without a course in petroleum geology (Judy). The fourth had completed a geology degree that included a course in petroleum geology (Amy). All four students had GPA's above 3.0 and had completed their B.S. degree just prior to the study.

The Geological Problem

The simulation. The geological problem that the students confronted was presented in the Geology Search simulation published by McGraw-Hill (Snyder, 1982). The simulation required that students search for oil using a map of a ficticious continent and a number of actions that the students could take in whatever way they thought would be most efficient and effective. The map was simple in that it showed only the outline of the continent, two river systems that ended in deltas, and a superimposed grid to locate where various different steps in the search would be conducted. The actions that the students could conduct were:

(1) a density scan ($25) that covered a square of 25 sections and showed the average density of the rocks below the surface.

(2) a core sample ($30) that showed one type of rock found under each of four adjacent sections. (It did not indicate what true core samples show, which is a cross section of the subsurface rocks. This note is important to understanding the actions of one of the students that are described later.)

(3) a seismic blast ($40) that indicated whether or not there was a potential oil bearing structure under one section by a "disturbance" in the lines representing the seismic reflection.

(4) the drilling of a well ($80) during which they would see a second look at the seismic blast results called an echo scan and picture of the cross section showing the actual structure of the rocks below.

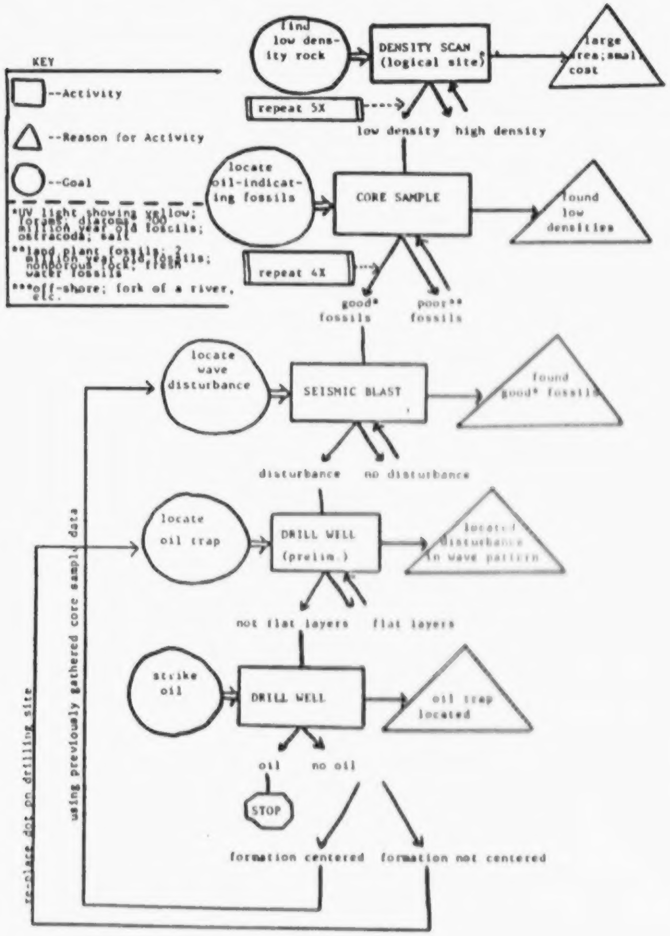
Once oil was found the students could also begin to sell oil and replenish the initial

budget they had been using to conduct the search.

In order to conduct the search effectively and efficiently students needed to be able to interpret each test an develop an optimal strategy for deciding what action should be taken next. The optimal strategy would begin with a density scan to locate low density rocks, continue with a core sample to locate the types of rocks that hold oil, then a seismic blast to located possible oil traps and finally the drilling of a well if a cross section of the rock layers shown on an echo scan confirmed the trap. The conceptual knowledge and procedural knowledge involved in an optimal strategy is represented in Figure 1.

This strategy and an associated list of all relevant propositions served as the basis for describing the students performance in terms of whether the propositions and strategies they used were correct or incorrect and complete or incomplete. They also were used as a frame of reference to determine when important information was missing from the students' background.

Geology Oil Search Simulation--The Ideal Methodology


KEY
--Activity
--Reason for Activity
--Goal
*UV light showing yellow; forams; diatoms; 300 million year old fossils; ostracoda; salt
**land plant fossils; 2 million year old fossils; nonporous rock; fresh water fossils
***off-shore; fork of a river, etc.
find low density rock
DENSITY SCAN (logical site)***
large area; small cost
repeat 5X
low density
high density
locate oil-indicating fossils
CORE SAMPLE
found low densities
repeat 4X
good* fossils
poor** fossils
locate wave disturbance
SEISMIC BLAST
found good* fossils
disturbance
no disturbance
locate oil trap
DRILL WELL (prelim.)
located disturbance in wave pattern
not flat layers
flat layers
strike oil
DRILL WELL
oil trap located
oil
no oil
STOP
formation centered
formation not centered
using previously gathered core sample data
re-place dot on drilling site

The textbook. The simulation was accompanied by a textbook that was simply written and included nearly all information that was needed to find oil. The goal of the game was given, each of the possible actions were explained, the appropriate circumstances for using each action were given as were the implications of the possible results for finding oil.

Procedure

Each student was asked to participate in the study for two 90 - 120 minute sessions. The first day they were asked to attempt the computer simulation of a search for oil with only the minimal instruction necessary to initiate the search. They were told that the goal of the game was to find oil, shown the map, and told what tests they could run. After they completed the first day they were asked to read and study the book that accompanied the program. After reading and studying the book during one evening the students returned the next day to attempt the simulation again.

Each session lasted approximately ninety minutes. During the session students were asked to think aloud as they attempted to solve the problem. They were specifically asked to provide their reasons for the goals they set, and the actions they took. A researcher reminded the students to think aloud and provide their reasons. The students' thinking aloud was recorded on a video tape recorder that was interfaced with the computer. The result was a complete visual record of all the computer screens which showed the students actions and the associated verbal reports of their reasoning.

Data Analysis

The data consisted of the videotapes of each session. The data was analyzed by determining the action sequences used during each session. Action sequences consisted of a numbered goal (G*), reasons for establishing the goal (G*R*), actions taken to reach the goal G*A*, reasons for taking that action (G*A*R*), data obtained by taking the action (G*A*D*) and the conclusions related to the data (G*A*C*). Relevant student comments were also included. Table 1 shows a portion of one of these sequences.

After complete action sequences were prepared descriptions of each students' performance were written. Each statement

Table 1. Analysis of Wendy's first session tape

G1	find rock types
G1R1	oil found in sed rock
G2	find shales
G2R1	shale contain fossil leaves
G2R2	leaves produce oil
G2R3	oil will be found in shales
G2A1	cs at river source
G2A1R1	shows rock type
G2A1R2	oil trapped between layers
G2A1R3	rivers start at high elevations
G2A1R4	there are more layers higher up
G2A1R5	therefore chances of finding oil are greater
G2A1R6	unporous rock can trap oil
G2A1D1	100 million years freshwater microfossils
G2A1C	(try some other place)
G3	find sea fossils
G3R1	might indicate oil
G3A1	cs at river source
G3A1R1	used to be sea area, river changed course
G3A1R2	do not understand sb or ds, comfortable with cs
G3A1D1	fossils, ostracods, UV, freshwater fossils
G3A1C1	(try some other place near river source)

Note: Action sequence G4 is deleted here so that sequence G5 which shows an attempt to learn new information can be included.

G5	find oil
G5R1	game goal
G5A1	drill well at new site near 2 m.y. old fossils and land plant fossils (near river source)
G5A1R1	running out of money
G5A1R2	adjacent area showed oil
G5A1R3	might have been a continuous forest
G5A2	obtain echo pattern
G5A2D1	echo shows flat, close and separated layers

Table 1. Analysis of Wendy's first session tape (cont.)

G5A2C1	separated layers are less dense, therefore oil could be found in them
G5A2C2	denser rock could contain oil
G5A3	drill the well
G5A3D1	dry well
G5A4	drill well near 100 million year old fossils (near river source)
G5A4R1	to see echo
G5A4R2	old fossils may have oil
G5A4C1	echo looks like dry well
G5A4C2	do not drill
G6	find what density scans indicate
G6R1	to assist in oil search
G6A1	run ds at previous location
G6A1R1	correlate ds with fossil type
G6A1D1	2.1 -2.4 values
G6A1D2	freshwater fossils
Note:	D2 information was taken from previous core sample
G6A1C1	cannot tell what densities indicate about fossils
G6A1C2	rocks with these densities are not porous
G6A2	run ds at another earlier location
G6A2R1	find area of higher densities
G6A2R2	correlate densities with fossil types
G6A2D1	100 m. y. fossils, ostracods, 2 m. y. fossils
G6A2C1	cannot tell what densities indicate
G6A3	run density scan at an untried location
G6A3R1	find area of higher densities
G6A3R2	correlate densities with fossil types
G6A3D1	2.7 - 2.9 values
G6A3C1	Need to know what the rocks are here
G6A4	cs here
G6A4D1	igneous and metamorphic rocks
G6A3C2	igneous and volcanic rock are not porous

used in the description was referenced to the appropriate section of the action sequence by goal number. For example, the description of Case 1 (Wendy) that is reported in the results section was taken in part from the initial action sequences shown in Table 1. The referencing system that was used was retained in the first part of this description as an example. The reference markers for the other descriptions are deleted because space does not allow the actual action sequences too be included.

Results

Case 1

Pretest. Wendy began her first session predicated on two misconceptions. One was that oil is associated with land plant fossils as indicated by the action sequences that began with goals G2, G5, G7, G10, G11. This misconception seems to be a "core conception" in that there are a number of elaborations and it is used in setting several search goals and determining the associated actions. The other misconception was that there is a better chance of finding oil at higher elevations than at other places because there are more sedimentary layers at those elevations. This misconception was used to decide that the majority of tests should be run at the sources of rivers since they are located at higher elevations (G2, G3, G4, G5, G6, G7, G8).

In addition to these misconceptions, Wendy included (1) a number of isolated incorrect propositions in her reasoning (e.g., separated layers are less dense (G5), denser rocks could contain oil (G5)) and (2) a number of imprecise conceptions (e.g., oil is found in sed rock (G2); unporous rock can trap oil (G2); sea fossils indicate oil (G3)).

Wendy also was plagued by missing knowledge. In particular, she did not understand what information would be gained by using several of the testing procedures. This resulted in a reluctance to use the density scan and seismic blast tests (G3, G4), the premature drilling of a well (G5) and an inability to interpret the results of tests that are run correctly (G3, G4, G8). For example, the data associated with G3 (land plant fossils, ostracods, an indication of oil through the use of ultra violet light

(UV), freshwater fossils) should have been followed by the drilling of a well at the UV site or the ostracod site. Missing knowledge may also have resulted in the failure to explore sites where there is a greater probability of finding oil (e.g., at the delta).

The state of Wendy's prior knowledge resulted in a strategy that at different times consisted of (1) searchs for oil driven by misconceptions, isolated incorrect propositions and missing knowledge (G2, G3, G4, G5); (2) attempts to use the simulation to learn new ideas that she believed were needed (G6, G7, G8); and (3) attempts to use what was learned (G9, G10). The portion of the strategy that was used to find oil was inefficient, ineffective, and inconsistent with the model strategy.

The attempts to learn and then apply "new" knowledge were somewhat more effective but quite inefficient. She was successful at learning that high densities indicated igneous rocks (G7), that igneous rocks were not associated with oil (G6), and that land plants were not associated with oil (G10). All these were correct. The later is especially important in that it implied she had set aside one of the misconceptions that was driving her initial efforts. However, the learning strategy was quite inefficient because it was based on the goal of matching specific densities with specific types of fossils and this cannot be done. The only additional learning that was observed was one case of "accidental" learning (G5) in which Wendy learned that the echo picture for a dry well showed no disturbances. The learning of this proposition was accidental in that it occurred during an action sequence that was part of a search for oil and not in a sequence that was an explicit attempt to learn from the simulation.

Posttest. Wendy's conceptual knowledge changed dramatically after her reading of the text. All evidence of misconceptions and incorrect propositions disappeared. However, there was still some missing knowledge about diatoms, about how to interpret a seismic blast, and an uncertainty about whether or not densities could be related to specific fossils. She did not attempt to solve the first two of these problems explicitly but compensated by ignoring the resulting data and using information from drilling wells that she now understood. She investigated the uncertainty about the density-fossil relationship directly. Her first goal was to compare data collected the previous round with density scan data, then conclude that densities cannot be correlated with specific fossil types. This was a return to the primary learning goal of the previous day -- the only such incident in the four cases. In short, she now seemed to know enough to compensate for missing knowledge and learn efficiently from the simulation.

The strategy Wendy used the second day also was quite different. She immediately recognized that there was a high probability of finding oil at the ultraviolet site that had been located the previous day. After concluding that densities and fossils could not be related, she immediately sought to find oil at the UV site. One step in the model strategy, the seismic blast, was omitted and a productive well was drilled at the site (G2). A second productive well was drilled near the first well using the model strategy and completely correct reasoning, except that she was unable to interpret the seismic blast. She knew that she needed to look for a "disturbance" but did not know what a disturbance looked like (G3).

Her next goal was to complete a density scan for the entire area in order to locate sedimentary and eliminate igneous rocks. This was not a particularly efficient strategy, however, it is logically defensible since there were no other competitors and her wells were producing enough income to support the effort. Completing this effort was time consuming. As a result, the session ended when all densities were recorded and Wendy was asked to return for a third session. No other student was asked to return for this additional session.

Added Session. The data in the third session indicated she had learned the optimal strategy and could execute it without any errors in reasoning. The only difference between her strategy and the model was that she had already run all the possible density scans and did not need to duplicate them. No indications of misconceptions remained and she had no difficulty interpreting the seismic blast pictures. She may have learned to interpret the seismic blast by continuing

to observe the results and interpret them in light of the data from the drilling of wells.

Case 2

Pretest. Mary's prior knowledge included the tentative beliefs that (1) oil is found in low density areas; (2) marine fossils indicate oil, and (3) disturbances in seismic patterns indicate "proper layers" for oil. These were correct. In addition, she incorrectly believed that freshwater microfossils would indicate oil. She was missing the knowledge needed to absolutely separate high and low density rocks, select probable oil producing sites, interpret the seismic blast picture, interpret the echo scan and cross section associated with drilling a well, and decide which fossils indicate oil. This case was quite different from the previous one in which a "core" misconception seems to be influencing the search. There seems to be no such "core" misconception here, but instead the search was influenced by an uncertainty about her knowledge and the missing knowledge.

Mary began the actual search for oil using the hypothesis that oil is associated with low density rocks and immediately attempted to learn whether or not that hypothesis was correct. After learning that she did not understand the initial density scan and seeing a second scan, she reasoned that the lower density values must be in the bottom half of the range of the first scan data. She then alternated between trying to learn from the simulation and trying to find oil. Her sequence of goals was to (1) determine the types of rocks that would be found, (2) find marine fossils, (3) learn what fossils could be observed and what information a seismic blast would provide, and then (4) drill for oil using fresh water microfossils as an indicator. Even if the action sequences designed to learn new information were not considered, this strategy did not approximate the model strategy .

Posttest. After reading the text Mary knew nearly all the information necessary to search for oil using the model strategy. She began the second session with an unsolicited description of the model strategy for finding oil, then proceeded to execute that strategy nearly without error in reasoning. The only difficulties were that she did not know all

the information needed to locate probable sites and that, like Wendy, she did not initially fully understand how to interpret the seismic blast pictures. The later problem she resolved during the process of searching for oil. However, there was one error in the interpretation of the seismic blast that remained. The seismic blast did not show a cross section as she believed. (The text probably was misleading in this regard). This error was not discovered by Mary because the design of the program does not result in errors when the incorrect interpretation is used. There were no explicit attempts to learn new information.

Case 3

Pretest. It was expected that the geology major, Jane, would know quite a bit more information that was relevant to the search for oil than did the other subject. However, the differences with respect to her knowledge related to oil searches was actually quite minimal. For example, she seemed only to know that oil can be trapped between layers and is not likely to be associated with fresh water fossils or igneous rocks. In addition, she incorrectly believed that oil would be associated with land plant fossils as did Wendy. This influenced her search for oil although not as extensively. As in the other two cases, Jane was missing quite a significant amount of information. She did not initially know what was necessary to interpret a seismic blast pattern, decide if oil was found in high or low density rock, or interpret a echo scan.

Two features of Jane's initial attempts to find oil were quite different from the preceding cases. First, she believed that core samples would show what rocks were found under a particular location with increasing depth, i.e, a cross section. This in fact is correct. The difficulty was that the simulation used "core samples" to show the rocks found under four different adjacent sections and did not provide information about the cross section. This is a case where correct prior knowledge resulted in explicit errors in decision making and interpretation and probably influenced the overall strategy that was used.

The second notable difference was that Jane made only one early attempt to learn from the program and did not try to learn

from the program again until the end of the session. It may be that more unsuccessful attempts to find oil were needed before she had exhausted her more extensive knowledge of general physical geology and learned she needed to know more that was specific to locating oil. The only new knowledge Jane learned was that high densities indicated igneous rocks. This occurred "accidentally" as she was seeking oil.

As for the strategy she used to find oil, it was not similar to the model strategy. The optimal sequence of decisions was not followed and information gained by one action was not used effectively in deciding the next action.

Posttest. The changes in Jane's background knowledge and the accompanying strategy following her reading of the text book were dramatic. There were no misconceptions, incorrect propositions, or evidence of missing knowledge. She followed the model strategy without an error in reasoning, located five producing wells and made no explicit attempts to learn more information.

Case 4

Amy's prior knowledge was extensive, correct, specific to searches for oil and used effectively. There were no indications of misconceptions or incorrect propositions. There was, however, one instance at the beginning of the first session in which her correct prior knowledge temporarily interferred with her ability to interpret the results of the density scan. There were also two instances in which she was missing information or at least was uncertain of what she knew. She initially did not know whether or not land plant fossils and 2 million year (M.Y.) old fossils indicated oil. In contrast with other cases, however, the missing information did not limit her ability to find oil. Amy was able to compensate by ignoring data related to these two indicators and using her knowledge of what she knew were indicators. It seemed that her more extensive knowledge base provided her an option of ignoring some data while acting on other data that was not available to other students.

Amy's strategy began with a density scan for which the data did not make sense to her. She later reported she had expected results associated with measurements of electrical resistance and could not interpret the information she was seeing. She then constructed an effective and efficient sequence of actions to learn what the density scan data meant and was successful. She did so by associating densities with rock types. It appeared that she knew what densities should be associated with different rocks and applied this knowledge to confirm her beliefs.

After Amy successfully found oil using the model strategy, she began two action sequences to learn the missing pieces of information. Near the end of the session and after she "had made enough money to find out were the dry formations were" she constructed two effective and efficient sequences of actions from which she learned that land plant fossils and 2 M.Y. old fossils did not indicate oil. Once this was done she returned to using the model strategy, although the session ended before more oil was located.

Posttest. During the second session Amy began searchs offshore and then in a delta. The selection of these sites reflected her knowledge of probable locations for oil. The strategy she constructed was to (1) find low densities, (2) core sample those low density sections until promising fossils were found, (3) conduct a seismic blast to locate structures, (4) examine an echo scan for a disturbance, and (5) drill a well if a potential oil trap was found. She did this series without an error in her reasoning. She found oil easily and frequently. After about 45 minutes of this the session was ended when she asked "Just how rich should I get doing this."

Summary of Results

The results described above can be summarized as follows:

1. Only the student whose knowledge was directly related to petroleum geology was able to develop an effective and efficient strategy for solving the problem during the initial attempt. Even the geology major was unable to develop an appropriate strategy without knowledge that was specific to the task.

2. The goals and actions students used to solve an unfamiliar problem were not limited to actions that are related to the problem goal. Each student also created explicit learning goals and actions. They recognized what they needed to know and attempted to learn what they needed to solve the problem. However, the amount of information learned in all cases was limited -- apparently too limited to allow the students to construct an adequate strategy for solving the problem.

3. Only the student with the knowledge specific to the task was able to use the simulation alone to learn efficiently.

4. Domain specific differences in students' prior knowledge influenced the strategies they tried to construct. For example, a misconception held by one student resulted in an ineffective and inefficient strategy as did a correct conception that lead to a misinterpretation of data. Missing knowledge influenced all students initial attempts. In three cases, the students were unable to construct appropriate sequences of However, in the fourth case, the student with

the nearly complete understanding of the domain was able to compensate for the missing knowledge in ways that were not available to the others.

5. For the three least knowledgeable students, the changes that followed their reading of the text were dramatic; (a) a misconception was set aside (although this actually may have occurred at the end of the first problem solving session); (b) there was only one explicit search for new information; (c) the students were able to compensate for the limited amounts of information that were still missing and ultimately learn that information; (d) the model strategy was adopted immediately by two of the three students and only slightly later by the third; and (e) the simulations were completed essentially without errors in reasoning.

Conclusions

Perhaps the most interesting aspects of this study were the clear indications that a significant portion of students problem solving behavior can be characterized as goal driven attempts to learn the information they needed to solve the problem and that a great deal of learning occurred subsequent to an initial attempt to solve a problem. When taken together these findings suggest what may be an effective instructional design. It may be important to initially provide students a relatively complex problem to solve before providing the portion of the instruction in which they are to learn new information. The initial exposure to the problem may teach them what they need to know to solve the problem. In some sense this is a form of individualized instruction. Each student must respond to the problem using his or her own prior knowledge. In doing so the student is likely to learn what of their knowledge is incorrect, what knowledge is missing from their background as well as what knowledge is already correct.

If the student brings a significant misconception to the task then the problem may provide the dissatisfaction with their existing knowledge that has been proposed as essential for accommodation to occur. Furthermore that dissatisfaction may be, as is probably essential, very accurate and very precise. A more generalized dissatisfaction with one's beliefs may only lead to frustration.

If a student begins with enough knowledge to interpret the problem correctly but not successfully solve it, he or she may learn exactly what they need to know --- that is, they may set specific learning goals that will guide their search for new knowledge during subsequent phases of instruction. If learning is goal driven as the students' initial attempts indicate then initial experience with the problem should result in more effective and efficient learning from any subsequent instruction.

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Preservice Teachers Conduct Structured Interviews with Children to Improve Instructional Methods

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While interviewing has been fruitfully used as a research tool for investigating learning in science (White, 1985, Osborne & Freyberg, 1985, Novak & Gowin, 1984), the step of translating this work into instructional methods has been difficult Efforts have focused on the use of research findings on children's concepts as a basis for structuring lessons and activities (Wandersee, 1986, Fisher & Libson, 1986). Children's concepts are relatively easy to uncover but extremely difficult to analyze The central questions of "How is information mentally organized?" and "What metacognitive processes are used to access this information?" have yielded answers which are difficult to communicate outside the interpretive methods of a research study

Much easier to convey to teachers and prospective teachers are the fascinating results obtained from listening to children explain their ideas Most parents and teachers have had the experience of hearing a child's spontaneous explanation

> 5 year old: **I can't get my slippers on!** [Your feet are hot and sweaty from being in your shoes.] **I need to stick them in the water to dry them off.** [You need to cool them off?] **Yes, that's what I mean, I need to stick them in the water to dry them off.**

What research in science education can offer is some insight into the importance of these ideas for

instructional purposes The specific instructional implications can be determined by the teacher after being given some training in eliciting and interpreting the meanings of student dialogue

Elementary education majors in their junior or senior year take a course in the curriculum of the natural and social sciences They are given the assignment to interview a group of children on a concept in science The purpose is to give these undergraduates firsthand experience in confronting the conceptions of their future students It is also designed to highlight the incompleteness of their own knowledge and the role this plays in teaching science which is itself an incomplete body of knowledge From this point on, the college students will be referred to as teachers

Interview Project

The components of the interview project included (a) the selection of a science concept and materials with which to demonstrate it, (b) interview planning based on an analysis of the materials, (c) tape recording a session with a small group of students, and (d) transcribing and analyzing the interview. Students were to select concepts about which they had some knowledge. The actual content of the interview, the questions, problems, and activities to be presented, were to be developed from the analysis of the activity materials

Analysis of Activity

The analysis was accomplished by the teacher stepping through the activity noting each action and the resulting observations The analysis became a sequence of statements of the following form

If I do this action, then I observe this result.

For instance, the concept is "poles of a magnet" and the materials are 2 bar magnets. The activity is to place the magnets near each other in various ways. The student would produce several statements of the following type.

If I place one pole of one magnet on the opposite pole of another magnet, then I see and feel the magnets attract.

If I place one pole of one magnet on the same pole of another magnet, then I see and feel the magnets repel.

Interview Plan

The list of action-observation pairs formed an "operational outline" for how the student perceived the activity. From this analysis they wrote questions and problems designed to get students to try the different actions just identified. They were told to pose problems and ask questions without telling the children exactly what to do. In addition they were to plan variations designed to test the stability of the children's responses. The operational outline along with the questions and problems became the "interview framework".

The teachers were to anticipate that the children would interpret the experience in a way that differed with their analysis. Children's responses would necessitate other questions, but as much as possible they were advised to stay within the interview framework. If children suggested new problems they were encouraged to explore them while considering what associations the children were making with the science concept.

Analysis of Dialogue

In their report of the interview session, the teachers were asked to consider several questions. What are the children's beliefs concerning this idea of science? What are some new questions or problems that would help you explore their ideas further during another session? Discuss other activities which were suggested by the ideas of the students. Was your own understanding of the science concept affected by this interaction with the children? Do you understand it better? Can teaching be made more effective by such close inspection of what children are expressing? What might be a "telling" question or activity at this age for revealing a child's understanding of this concept?

Results

The teachers gained as much from observing themselves in this process as they did in listening to the children. It was quite common for them to evaluate the methods they were employing and their effects on what they perceived to be student learning.

> 1. I really thought that the group would have grasped the concept of balance point from the first series of demonstrations. After reviewing the tape, it was evident why they had not--I didn't allow them to! I directed all the questioning.

Their lack of experience lead them to assume that they could apply "fixes" the next time they did this activity to "correct" some of the problems that occurred.

> 2. The students seemed to be concerned that (clay impressions) couldn't really be fossils, they weren't old enough. Perhaps I needed to stress more that fossils are records and can be, usually are, old

The realization that students were expressing important ideas that didn't necessarily need "fixing" eventually asserted itself in some way. Some teachers became more sensitive to the shortcomings of the instructional process and were willing to turn some of the responsibility for learning over to the students and the materials.

> 3. If I would have told these kids every step to take, they would not have learned nearly as much as they did by their own trial and error. Now, they not only know and understand what a magnet can do, they know and understand what it cannot do as well.

These teachers became sensitive to the role of dialogue in the instructional process. Reviewing the tape recording revealed important statements which were missed during the lesson. Many felt that if they had "heard" these comments they could have used them to the advantage of the group. They also "heard" themselves cutting student-student dialogue short and limiting students with their overly narrow questions.

Clearly the most interesting result of these interviews were the ideas of the children. The teachers were often surprised to notice the responses of children and how they differed so markedly from what they expected.

> 4. I thought at least half the class (small group) knew the concept. Not so! "Greg, who I was sure was on the right track (in finding the center of gravity), bent feet on his shape, stood it upright and announced that he had it balanced on its center of gravity.

There was an indication in some cases that the ideas of children were affecting the concepts of their teachers, yet the teachers did not always recognize it. Quote 2 above suggests that the teacher had never really considered the aspect of age in the concept of 'fossil' and probably didn't have a clear understanding of the geologic processes involved with forming a fossil. Yet, she commented, "Their comments really made me stop and think, I wasn't as sure of the concept as I thought." Another student, however, confused the concepts of 'force' and 'work' and essentially conducted her interview about 'force' leaving 'distance' to play an insignificant role. She was unaffected by a child's statement that the box weighed more going up the ramp than being lifted because it had to be pushed up hill.

Some teachers did recognize the need for a depth of knowledge as a result of children's responses. One teacher became aware of the role 'pressure' was playing in an activity on popping corn where before the interview 'gradual' and 'rapid' expansion were the central concepts. Others saw that knowledge was of two types. There was knowledge about science concept and knowledge of children's thinking. Some concluded that they needed to know more about how children formed ideas. The teacher who was popping corn summed in up this way:

> 5. The point being, that the more a teacher knows about a subject or subjects the easier it would be to infer the meaning behind students' words.

An unexpected result of the interviewing activity was the degree of confidence it produced in dealing with science concepts. A common concern of preservice teachers is their uncertainty of what to do if the children are not following their lesson Underlying this concern is the fear that the children will become hard to handle This fear is often translated into overly restrictive classroom practice which limits student inquiry

The controlled environment of an interview with a small group of children seemed to lead to a more relaxed approach to the subject matter One student who was highly structured in his approach to lesson design and also quite uncomfortable with math and science commented

> 6 I was even pleased when I saw it (the activity) was not going well, that I was perceptive enough to adapt to that situation and as a result, accomplish my objective

There was less pressure on the teacher to "perform" with science knowledge The emphasis was on what the student knew about the subject In this way the teacher could respond in a collaborative way and enjoy the exchange rather than feel it necessary to be critical

> 7 I was very nervous at first because I did not know much about shadows As time went on, the children had such great observations that they got my mind rolling

Summary

These preservice teachers were enlightened and in some ways charmed by the notions the children expressed The teacher in Quote 7 used geometric shapes to create silhouettes and found her second graders calling them "cheese", "a house", "a piece of pie", or "melting ice cream" Being able to enjoy and reflect on statements of this type made the teachers feel in touch with the

children and less apprehensive about using their own science knowledge

While the teachers were not as critical of the children, they were far more critical of their own performance This is a sharp contrast to self and peer evaluations of micro-teaching activities After reviewing the tape, the teacher working with the 'center of gravity' wrote

> 8 I remember thinking how well it was going the students were responding on cue, the lesson was well organized By the end of the activity they had performed up to my expectations, but they had not learned a thing

These teachers were calling for more student-student dialogue, the need to spend more time on a single activity, children performing the activity for each other and their parents, and evaluations based on observing children in action They observed that children, even those in the upper grades, say things just to please the teacher This conveyed the thought that learning is harder to identify than is suggested by paper and pencil evaluations

This interview project conveyed a sense of what quality time in an instructional setting was like The steps necessary to produce this kind of instruction in a whole class is not easy, but these teachers came away with increased confidence that they could discuss science with children

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Using Hierarchical Concept/Proposition Maps to Plan Instruction that Addresses Existing and Potential Student Misunderstandings in Science

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In order to help teachers develop instructional plans that address student misunderstandings, a planning technique has been devised where teachers construct and use concept/proposition maps (unit maps) to lay out what is to be taught and to identify possible areas of misunderstanding by students. The maps are organized around categorical concept hierarchies and cover the content of a microschema or unit. On the maps are diagrammed facts, concepts, propositions, attitudes, science processes, and physical skills to be taught during the presentation of a unit of instruction. The information is diagrammed in a way which shows the interrelationships among the content. Once the content of the unit has been mapped, the information is reviewed in each of the areas of knowledge to locate potential misunderstandings on the part of students prior to or during the teaching-learning process.

According to Gagne (1987), there are five major learned human capabilities. These are: verbal information, intellectual skills, cognitive strategies, attitudes, and motor skills. Verbal information can be further categorized (Gagne, 1970; Eggen, Kauchak, & Harder, 1979; Ausubel, Novak, & Hanesian, 1978) into stimulus-response learning (facts), categorical concepts, and rules (propositions, generalizations or principles). As an information processor, the learner is clearly able to form concepts and propositions in addition to actively pursuing the acquisition of facts (Eggen, Kauchak, & Harder, 1979).

Although having a large store of accurate knowledge is a prerequisite for successful learning and problem solving, the structure in which this knowledge is stored is also important. According to Reif (1983) and Resnick (1983), most students have a store of knowledge that is small, not well organized and full of well established misconceptions, while the knowledge base available to successful learners and problem solvers is large and well organized (Eylon & Reif, 1979; Frederiksen, 1984; Smith & Good, 1984; Stewart, 1982a, 1982b, 1983).

There are numerous techniques that can be used to help learners organize their knowledge store. Knowledge vee Diagrams, advance organizers, lesson outlines, and concept maps are a few of these techniques. Concept mapping has been shown to be a powerful and successful technique when used in instruction (Eylon & Reif, 1979; Novak, Gowin, & Johansen, 1983; Stewart, 1983). The quality of student knowledge is improved when concept mapping can be used to identify and correct student misconceptions. Students, as well as teachers, can be trained to use concept maps to organize their own knowledge.

As part of the instructional planning process, teachers should reflect on the possible misunderstandings their students might possess. Instruction needs to build on the foundational knowledge of students. Teachers should consider the prior degree of understanding of the topic to be taught and work to expand and refine the cognitive structures of students. However, unless teachers consider the misunderstandings held by students, instruction might be overwhelmed by these misunderstandings. Unless misunderstandings are directly addressed, students may be so confused or 'hung up' that they are not able to pay attention to the new content being taught. Students may think that they already know the topic and the new material makes no sense, they may become frustrated because of apparently conflicting information, or new content might not fit with personal foundational knowledge that is predicated on misunderstandings.

As a way of being better able to identify possible misunderstandings it is helpful to categorize them into types paralleling the domains of knowledge. By classifying the misunderstandings, insight can also be gained into ways of addressing or correcting the inaccurate knowledge. For example a misunderstanding about a categorical concept might be addressed by explicitly using a nonexample of the concept which 'short circuits' the misunderstanding or causes the student to appropriately limit the range of the concept.

Here in consideration of the different types of misunderstandings and in the unit maps, knowledge is categorized into the cognitive, affective, and psychomotor domains. The cognitive domain is further divided into the areas of singular facts, categorical concepts, propositions (generalizations or principles), and science processes (intellectual skills). The affective domain is addressed through the identification of attitudes (composed of feelings, beliefs, and actions). Physical skills fall within the psychomotor domain.

Within the cognitive domain knowledge is carefully partitioned to fulfill the following definitions. Facts are defined as content which is singular in occurrence and acquired solely through the observation of events, occurring in the past or present (Eggen, Kauchak, & Harder, 1979). Concepts are abstractions made up of the criterial attributes that a given category of objects, events, or phenomena have in common (Ausubel, Novak, & Hanesian, 1978). Propositions (principles) are formed by chaining two or more concepts (Gagne, 1970) or are a meaningful relational combination of two or more concepts, yielding a new idea (Ausubel, Novak, & Hanesian, 1978). Relationships between concepts that are

only hierarchical are not considered here to be propositions. Intellectual skills are any of the well recognized science processes that are used to collect, organize, and manipulate data, or create new knowledge.

Categorization of misunderstandings done according to different types of knowledge yields the following system.

Misfact - memorized factual knowledge which is wrong

Avogadro's number is 6.023 X 10^{25}.

The side of the Moon not facing Earth never receives direct sunlight.

Misconception - inaccurate understanding of a concept, misuse of a concept name, wrong classification of concept examples, confusion between different concepts, improper hierarchical relationships, over- or under-generalizing of a concept

Frogs are reptiles.

The eight planets and the Earth rotate around the sun.

The Earth revolves on its axis.

Vertebrates are a kind of mammal.

Mass and weight are the same thing.

Seals are a kind of fish.

Misproposition - wrong or inaccurate propositions, improper application of propositions, merging of two or more propositions, over- or under-generalizing of a proposition

The heavier an object is the faster it falls.

Charles' Law is used to determine the new volume of a balloon as it is moved from the surface of a lake to 30 feet below the surface, assuming the thermocline to be at 40 feet.

A student decides that the reaction between sodium and fluorine gives off less heat per mole than the reaction between sodium and iodine.

Tissues are made up of organs.

Metals are a type (or category) of element.

Misbelief - a cognitive misunderstanding which leads to a consequential attitude

Snakes are cold and slimy.

Scientists seldom make mistakes.

The bible is precisely accurate.

Mismanipulation - physical manipulations done improperly or ineffectually

Pictures taken of a nonmoving object with a Polaroid camera are in focus, but blurred.

A student punctures the palm of the hand while inserting a thermometer in a rubber stopper.

Processing mistake - inaccurate or illogical thought processes such as classifying mistakes, improper interpreting of data, failing to control variables; the misuse of any of the science processes (characterized by Piagetian cognitive task mistakes)

As a student investigates the factors that influence the growth of plants, the amount of water applied and the amount of sunlight allowed are varied simultaneously.

A student counts the legs on an ant and gets eight.

A student determines that there is no relationship between the length of time a force is applied to an object and the velocity of the object, since each time the experiment is done slightly different results are obtained.

In order to facilitate the recognition and identification of possible misunderstandings, as well as to aid a teacher in more easily perceiving the complexity, interconnectedness, and extensiveness of the content to be taught, unit maps are developed and used. Unit maps graphically present a cognitive structure of a microschema of content and include facts, concepts, propositions, science processes, physical

skills, and attitudes. The directions for the production of a unit map follow.

The purpose of this exercise is for you to practice the use of a method of planning and analysis of a quantity of instructional content. You will focus on a unit of instruction. A unit is typically a single chapter in a text or a few closely related short chapters and where the instruction will typically last for about two weeks. During the exercise you will list pertinent facts, concepts, and propositions your students would be expected to learn as well as science processes to be developed, attitudes to be formed or preserved, and physical skills to be developed. Further, you will graphically show the interrelationships among these entities.

1. Obtain a sheet of 17 x 22 in. or 24 x 36 in. paper and two or three fine tipped colored marking pens.

2. List the concept names included in the chapter (toward the center of the paper) in strict categorical hierarchies. It is probably best to also include concepts that are closely related to this unit but which appear in previous and following chapters. You will typically end up with three to ten hierarchies.

3. List facts (at the bottom of the paper) included in the unit that are so important that students would be expected to commit them to memory. Concept definitions would of course not be listed.

4. Connect two or more concepts with a line to show a mutual relationship in the form of a proposition. Do this for each important proposition in the unit. Lines connecting higher order (more abstract) concepts form higher order propositions.

5. List propositions (down the right side of the paper) as complete statements and in an outline format to show their hierarchical relationships and label the corresponding lines connecting related concepts.

6. List the science processes you wish to develop (at the upper left of the paper) coding these processes to the cognitive information to be learned in conjunction with the processes. (Use colored dots.)

8. List physical skills to be developed (at the middle left of the paper), coding to cognitive information.

7. List the attitudes you wish to form or preserve (at the lower left of the paper).

Once this comprehensive listing of content has been diagrammed instructional objectives can be written, possible misunderstandings can be identified for each of the content areas of the map, resources identified, instructional activities devised, and assessment instruments produced. Of most importance, the planning and delivery of instruction is more likely to proceed in an integrated and meaningful manner. This is probably especially true for teachers who have produced their own maps rather than those using a map drawn by someone else.

Instruction might proceed according to any of a number of instructional models. Deductive model, inductive model, and Ausubel model lessons (Eggen, Kauchak, & Harder, 1979) can be designed drawing from the concept and proposition hierarchies displayed on the map. Instruction seems to proceed best when examples are used to clearly illustrate and delineate concept categories (Joyce & Weil, 1980) and to illustrate propositions. Misconceptions and mispropositions can be counteracted, curtailed, or prevented during the instructional process through the judicious use of examples and nonexamples when illustrating concepts and propositions.

Examples are chosen from the mapped concept or proposition hierarchies from subordinate levels. Since the map graphically displays subordinate levels, a full and valid range of examples can be more easily and accurately chosen. Nonexamples might typically be drawn from coordinate categories and delimit the range of a concept category or the applicability of a proposition. Deductive lessons proceed downward through the hierarchies from a statement of a concept definition or a proposition through examples taken from subordinate levels. Inductive lessons proceed upward with the presentation of examples or illustrations and with students developing concept definitions or statements of propositions which are superordinate to the examples.

Ausubel model lessons present the content of entire concept or proposition hierarchies first downward (progressive differentiation) and then roughly upward (integrative reconciliation).

Teachers report that this planning technique is very powerful, exhaustive, and helpful and also extremely time consuming. The method has been used for about three years with undergraduate students, experienced inservice teachers, and with corporate trainers. Almost all teachers and teachers in training initially experience considerable difficulty in conceptualizing the task before them. Much of their distress is related to the task of discriminating between the different types of knowledge, especially facts, concepts, and propositions. Once a map has been produced, the elegance of a variety of instructional models is immediately apparent to teachers. The execution of the planning and delivery of instruction seems to be considerably enhanced. Most teachers spontaneously express their delight in gaining new insights into the interrelatedness of the content they teach. Furthermore, teachers seem to be much more attuned to the misunderstandings that might exist or occur in the variety of knowledge areas.

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MISCONCEPTIONS ABOUT WATER PRESSURE

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Introduction

Children may have a variety of experiences with water--turning on a faucet, driving past a city water tower, swimming in a lake, standing on a man-made dam. Developing an understanding of water pressure should help children make sense of the world around them.

Children's understanding of water pressure has been the subject of science education research. Engel Clough and Driver (1985) interviewed 84 students between 12 and 16 years old and concluded that students commonly consider pressure in liquids to be only downward. The proportion of students who used the idea that pressure increases with depth was 60% for 12-year-olds, 73% for 14-year-olds, and 88% for 16-year-olds. When students did consider pressure to be in other directions, it was often pressure associated with movement of liquids.

Procedures

The study reported in this paper was conducted to investigate students' understanding of and thinking about water pressure, particularly concerning the ideas that pressure increases with depth and that pressure at a given depth is equal in all directions. An entire class of 13 students (5 boys and 8 girls) participated in this study. All were 14 years old except one boy and one girl who were 13. The students were in an eighth-grade program for the gifted. They were selected for the program by the school psychologist using criteria of achievement on standardized tests and success on school assignments.

The first day of the study the students took a written pretest consisting of twenty questions. Sample questions are shown in Figure 1 (on the last two pages of this paper). After all the pretests were turned in, a demonstration was performed and a discussion was conducted with the entire class. The topic was the difference between pressure and force, including English units used to measure each. On the second and third days, students were interviewed in groups of three or four. The students discussed some of their written responses on the pretest and answered more questions based on the previous day's discussion. On the fourth day, the class met as a whole group for demonstrations, hands-on activities, and discussion. The topic was motion due to unbalanced forces and motion from regions of high pressure to regions of low pressure. On the fifth and sixth days, interviews were conducted similar to days two and three, except with emphasis on the application of generalizations about water pressure to everyday objects like city water systems and hydroelectric dams. Then, on the sixth day, the students took a written posttest that was identical to the pretest. All of these activities were recorded on videotape.

Results: origins of students' ideas

Before considering what generalizations the students used during the activities listed above, it is important to examine how students may have developed those generalizations. Having an understanding of the origins of students' generalizations is a prerequisite to helping students recognize generalizations that are not scientifically acceptable. Sutton (1982) has classified the origins of students' ideas as (1) direct physical experience, (2) available language, especially metaphors, (3) peers' beliefs and opinions, and (4) formal and informal instruction.

The gifted eighth-graders mentioned sources of ideas from the first and fourth categories; however, no student remembered any extensive instruction about the topic. Some students did remember having a little prior formal instruction about water pressure, but they did not remember doing any hands-on activities as part of that formal instruction. Students did refer to direct experience with objects outside of school, such as watching coffee drip out of a small hole in a disposable cup. Students mentioned informal instructional sources of information; most commonly mentioned was television documentaries about diving in the ocean. One student mentioned seeing cartoons in which bullets were shot into barrels of water. (Maybe that is too informal to even be considered instruction.)

Watching the students interact during the interviews made it evident they were deriving ideas from their peers (Sutton's third category). When asked the amount of pressure exerted by air under normal atmospheric conditions, most students were reluctant to volunteer. Once someone answered, every answer in that group was close to the first answer. Answers within groups varied by no more than a factor of 5 in spite of the fact that answers between groups varied by factors as great as 200,000.

The limits of language were, at times, demonstrated by the students' written and spoken words. When asked on the pretest for "your definition of water pressure," some students left the answer space blank or gave circular definitions, for example, "amount of pressure on each cubic unit of something under water." Their definitions on the posttest were not much improved.

On the pretest, only one student attempted an operational definition, and even it was inaccurate "the ammount (sic) of resistance measured by a water valve" and followed by the more usual response "and the weight of water pounding on a substance." On the posttest, only this one student gave the definition of "force divided by the area of an object." That one student, on the posttest, also retained her previous definition with slight rephrasing, "ammount (sic) of weight being pulled, pushed down by gravity."

On the posttest, another student gave as a definition of pressure "amount of pounds per square inch," and that was the one other response counted under the category of force per unit area. It might have been expected that more students would give responses of this type. One the first day of this study (after the pretest) in front of the entire class, "P=F/A" was written on the blackboard and the concept of force on one unit of area was explained. Then students solved and discussed problems concerning the pressure exerted by a box in different orientations on a table (given the dimensions of the box and its weight).

As shown in table 1, most of the students said water pressure was "force" or "weight" of water. The totals are more than 13 because some students gave more than one definition and each definition was counted.

Table 1: Students' definitions of water pressure

Answer	Frequency	
	Pretest	Posttest
force/area	0	2
force or weight of water	8	9
amount of water	3	2
missing or circular answer	3	2

When asked for words associated with water pressure, the most frequent pretest answers were faucets, fire or garden hoses, and waterfalls. It is interesting that all of these answers specify objects from which water can be seen to be moving. Objects listed frequently on the posttest, but not at all on the pretest, were dams, aquariums, and water tanks. All of these were discussed with students during the study. The number of students who listed swimming pools increased, also, from pretest to posttest.

Feher (1983) has classified students' responses about a particular phenomena and/or objects as arising from (1) previous experience with similar physical objects, (2) analogies drawn with different physical phenomena, (3) expectations about the situation in which the questions are asked, particularly about the inclusion of redundant, inconsequential, or superfluous information, and (4) extensions of ethical codes, particularly in the absence of explicit clues as to how to solve a problem. Feher's first two categories seem close to Sutton's first two, but the others are distinct. Feher's last two categories cover influences that are real, but are difficult to ascertain. None of the gifted students in this water pressure study made an estimate of the height of an eight-inch can when that number was needed to solve a proportion problem correctly. This was probably due to an influence in Feher's fourth category. A similar problem (see question 14 in Figure 1) with all the information provided was solved correctly by 85% of the students on both the pretest and the posttest. (The other two students neither answered the question correctly on the pretest nor on the posttest.)

Each student seemed to have incorporated, prior to this study, parts of ideas from other sources without consciously examining any idea for consistency with his/her other beliefs. Some of the inconsistency may be due to students holding on to two domains of knowledge, one for the everyday world and one for science lessons (Solomon, 1984). At least one student during the pretest and more students during the last interview began looking at the consistency of their beliefs. For the analysis of the pretest and posttest results, similar questions were grouped together, and a student's responses were counted as correct only if all the questions in the group were answered correctly.

No evidence in pretest or in the early interviews indicated that the students had reasoned through the consequences of their beliefs about water pressure to see if those consequences matched the phenomena observed in the world around them.

Results: students' use of generalizations

Of the two generalizations focused on during this study, students understood that pressure increases with depth better than they understood that pressure at a given depth is equal in all directions. Table 2 gives the frequency of students who consistently used generalizations correctly in responding to questions asking for comparative statements (see questions 10, 13, and 15 in Figure 1), not for calculations based on proportions (see question 14 in Figure 1).

Table 2: Students' consistently correct responses

Generalization tested	Frequency	
	Pretest	Posttest
vertical pressure is directly proportional to vertical depth	6	11
horizontal pressure is directly proportional to vertical depth	0	6

Students discussed their answers to some of the questions on the pretest with the two or three other students in their interview group. However, the students were not given the scientifically acceptable answers because rote learning was not being encouraged. Students were not given an opportunity to discuss all their answers during the interview so that for certain posttest questions students would know only their past answers, not other students' answers. Maybe students discussed the pretest at other times; however, adolescents outside of classroom situations usually talk about things more captivating to them than answers to a nongraded test.

Students were asked, also, to make a diagram of water coming out of holes in a can (see question 20 in Figure 1). On the pretest, only two students correctly showed that water from the bottom hole would move the greatest horizontal distance before reaching the catch basin. All thirteen students drew the correct picture immediately after a demonstration using the can. On the posttest, twelve students drew the picture correctly and one remaining student left the answer space blank.

A misconception often stated by students was that horizontal pressure at a point on an object is directly proportional to the horizontal distance from that point to the nearest boundary of the water (not crossing through the object). The misconception seems to be an incorrect extension of the acceptable generalization of the proportionality of vertical pressure on a point and vertical distance from the point to the upper boundary of the water.

It is interesting to contemplate a world in which the misconception would reflect reality. Except for an object exactly at the center of a body of water, all objects in water would have more horizontal pressure on one side than another with the ratio of the pressures equal to the ratio of the horizontal distances from the water boundaries. Therefore, any object set off center in a body of water, would be pushed towards the closer boundary of water with ever increasing force. The acceleration of the objects would be increasing, too, so extremely large velocities could be attained in a body of water such as the ocean.

No student thought of the logical consequences of this misconception until the consequences were presented by the researcher through demonstrations, hands-on activities, and discussion. During interviews conducted on the next two days, students in two of the four interview groups, without prompting from the researcher, extended the idea of motion due to unbalanced forces to relationships between pressure upward on the bottom of a jar, the pressure downward on the top of a jar, and the weight of the jar. The arguments of students in those two groups were more logical than anything that had occurred in the small group interviews or whole class discussions previously.

The posttest results reported in Table 2 show that some, but not all students replaced their misconception with the scientifically acceptable generalization. Some students continued to accept parts of ideas without accepting the whole. For example, when comparing the pressure on a fish's back with the pressure on its mouth, a student wrote, "More water pressure is exerted on the striped fish downward than from the side. If the pressure was from the side, it would not 'stand' still."

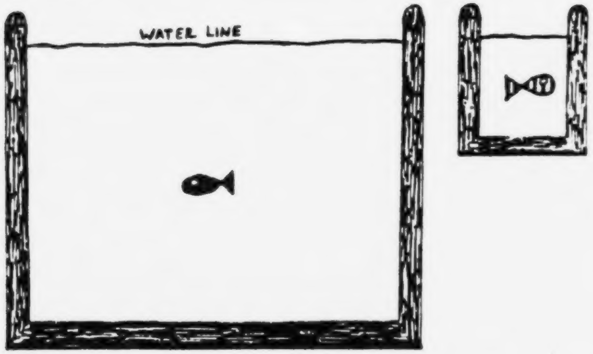
Conclusions

This study indicates that, when given opportunities to observe demonstrations, to handle concrete objects, and to participate in discussions that are structured around the students' misconceptions, some students can make progress in changing from prior beliefs to scientifically acceptable generalizations about water pressure.

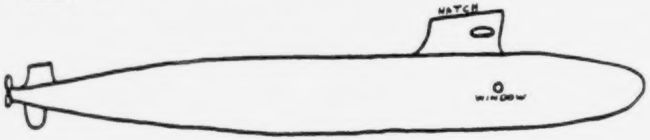
The obvious conclusion is that science education researchers need to continue to learn about modes of instruction productive for encouraging change in students' beliefs as well as to learn about their commonly held beliefs.

Figure 1: Sample questions from pretest and posttest

8. The black fish swims to another position as shown in the cross-section drawing below. Is the downward water pressure on the top of both fish the same? If not, which fish has more pressure on it? Give your reasons for your answer.



13. A submarine is lying on the sea floor 300 feet below the surface of the water as shown in the perspective drawing below. The downward water pressure on the hatch is 9 atmospheres. Approximately what is the sideways pressure against the outside of the window? Give your reasons for your answer.



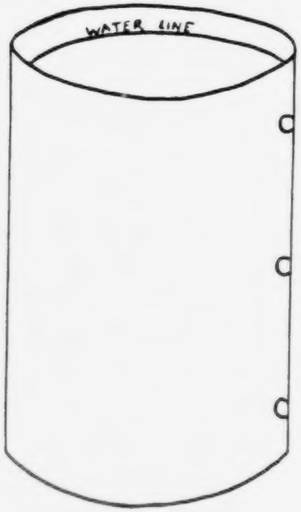
14. A submarine is lying on the sea floor 300 feet below the surface of the water as shown in the perspective drawing below. The downward water pressure on the hatch is 9 atmospheres. After the submarine rises 100 feet, approximately what will be the downward pressure on the hatch? Give your reasons for your answer.

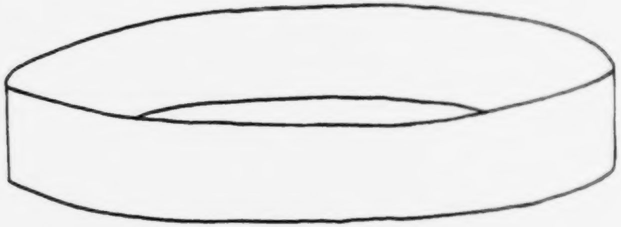
15. When the submarine is 100 feet above the sea floor, approximately what will be the sideways pressure against the outside of the window? Give your reasons for your answer.

Continuation of Figure 1:

Sample questions from pretest and posttest

20. Three plugs are pulled simultaneously out of the three holes in the can as shown in the perspective drawing below. Draw arrows showing the movement of water through the holes and into the catch basin drawn at the bottom of the page. Give your reasons for your answer.





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WHAT TO DO FOR SCIENCE MISCONCEPTIONS*

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During the last decade there has been an increasing interest in science misconceptions (and very particularly in physics). One of the main questions this research has faced is, of course, what to do about science misconceptions, and we intend to review in this paper the different answers given to this question, in order to clarify the implications of research in the teaching/learning process.

1. NOTHING TO DO?

Misconceptions -at least those most deeply rooted- are associated with intuitive ideas or preconceptions acquired prior to school learning (Driver 1986). And for some authors (Preece 1984), these ideas are not just learned from experience but "built into the hardware of the brain... The Kantian hypothesis -that many of the templates by which we structure the world are innate rather than constructed- provides a parsimonius explanation of much that is known about children's science. In particular, the persistence of intuitive views in the face of contrary teaching and their widespread occurrence would be natural consequences of their innate basis. Furthermore, the existence of an innate triggering hierarchy would account for the parallel between ontogenesis and phylogenesis".

If we accept Preece's hypothesis we should almost give up trying to change the intuitive ideas of our pupils. But Preece's explanation is not as parsimonius as he affirms: it can not even explain how the pre-classical conceptions were changed historically or how an innegligible percentage of students manages to learn significantly classical physics.

To prove that their alternative frameworks are constructed and not simply triggered, we have asked students how sure they were of their answers to questions on, for instance, the force/movement association; and we have found out that the idea of force as the cause of movement was sustained much more strongly by university students than by younger pupils (see fig 1). But, of course, the best way of proving the inconsistency of Preece's hypothesis is to show that a conceptual change from intuitive ideas to scientific knowledge is not as difficult as it would necessarily be if intuitive ideas were really innate, "built into the hardware of the brain".

2. IS IT NECESSARY TO BOTHER ABOUT MISCONCEPTIONS?

Some researchers on science misconceptions such as McClelland (1984) support ideas which are just the opposite of those of Preece (1984). McClelland affirms that pupils have no alternative conceptual frameworks: the real reason for their misconceptions is a "strategic inattention" when they are obliged to answer questions on physical phenomena which are not relevant enough for them. It is true that young pupils give very quick answers, without paying too much attention. The trouble is that misconceptions do not affect just children: some of these errors -particularly those in the domain of mechanics- are commited also by university students and even by secondary school teachers. As we have shown in a study involving over 100 secondary school physics teachers (Furio and Gil 1983), (Carrascosa 1987), more than 60 % gave an incorrect answer to one or more of the following true or false propositions:

(1) If the resultant force on a body is zero, the body will be at rest.

(2) The movement of a body always takes place in the direction of the resultant force.

(3) If the velocity of a body is zero at a given instant, the resultant force at this instant must be zero as well.

The questionnaire contained 7 other items and all the answers to these likewise revealed the persistence of intuitive physics. The existence of deeply rooted preconceptions and the difficulty in their substitution by scientific concepts can thus neither be denied nor interpreted as a result of strategic inattention of children. We really need, in conclusion, to bother about misconceptions.

3. SCIENCE LEARNING AS A CONCEPTUAL CHANGE

One of the most important results of research on science misconceptions has been, undoubtedly, a better understanding of difficulties in science learning and the awareness of the necessity of deep changes in the teaching/learning process, to improve meaningful learning.

Particularly important in this sense have been the proposals of conceptual change strategies (Posner, Strike, Hewson and Gertzog, 1982), based on the assumtion that many difficulties in science learning have their origin in the knowledge pupils have acquired prior to instruction and in the ignorance of this knowledge by teachers. Posner et al (1982) view science learning as an activity similar to research -or, in other words, to the construction of scientific knowledge- where the conceptual change should be the equivalent to Kuhn's paradigm shift.

The idea of science learning as a process of *knowledge construction* starting necessarily from prior knowledge, appears, more or less explicitly in recent proposals by many authors (Driver 1986; Gil 1983; Osborne and Wittrock 1985; Novak 1986). We can speak then of the *emergence of a constructivist model for science learning* which integrates recent research on science education with many other contributions (Bachelard, Piaget, Vigotsky,...). As Novak (1986) says: "The exciting thing that is happening now is that we are beginning to do the kind of research and instructional innovation that builds on our new psycological and epistemological insights and is leading to promising new educational programs (...) We are moving towards research that shows the important interplay between thinking and feeling and the parallels between the construction af meaning by learners and that done by creative mathematicians"... and -we can add- scientists.

But, is this conceptual change possible? Can pupils construct scientific knowledge which desplaces their intuitive preconceptions?. Some experimental results (Hewson and Hewson 1984) seem to suggest that an instructional strategy based on the model of conceptual change causes a much better acquisition of scientific conceptions than the usual mere transmission/reception of knowledge. Nevertheless, other authors (Fredette and Lochhead 1981; Shuell 1987) stress that conceptual change is often very difficult, even when prior conceptions are explicitly considered.

We touch here an essential point: can we really do anything to improve a significative learning of science and to remove misconceptions?. In our opinion, a positive answer to this question can be obtained by looking more closely at the parallels between the construction of meaning by learners and that done by scientists.

4. SCIENCE LEARNING AS A CONCEPTUAL AND METHODOLOGICAL CHANGE

As we have already mentioned, the importance of pupils' conceptual frameworks and the need for orienting learning as a conceptual change, can be based on the existence of a certain isomorphism between a scientific research process and significative science learning (Piaget 1974; Posner et Al 1982; Gil 1983; Saltiel and Viennot 1985; Novak 1986). One can understand, from this point of view, the difficulties of bringing about a conceptual change, since this can be equivalent to what historically represents a scientific revolution. Moreover, this isomorphism enables us to predict that it is not enough to take into account pupils' preconceptions, to produce the conceptual change: effectivly, the resemblance between pupils' intuitive ideas and preclassical conceptions can not be accidental but must be the consequence of the same way of approaching problems. And it is easy to show that both children and preclassical works on science, approach problems in a very similar way, that we have called "methology of superficiality" (Gil and Carrascosa 1985). This methodology consists of common sense evidence, and of coming to conclusions based on qualitative observations. That is the way of thinking which led Aristotle to write (in De Caelo): "A given weight covers a certain distance in a given time; a bigger weight covers the same distance in less time, being the times in inverse proportion to the weights. So, if a weight is double the other, it will take half the time for a given movement". And this is, in our opinion, the methodology which leads pupils, and even university students to think that "a body which doubles another in mass falls down in half the time the latter one would take".

We have recently studied in datail how pupils (and teachers!) thinking respond to this superficial approach, how they give answers, with full confidence, which are generalizations of qualitative observations. Particularly we have shown that high school pupils, university students and teachers in service and in training, express statements like "a body always moves in the direction of the resultant force" with a very high degree of confidence, even when they are warned on how easy it is to make mistakes about these apparently simple questions.

We have also measured the time used in answering these questions: the answers were almost inmediate (especially those of teachers!) showing an evident lack of reflection.

We could summarize saying that alternative frameworks are associated -as common sense physics was- to a methodology characterized by certainty, by absence of doubts or consideration of possible alternative solutions, by quick and very confident answers based on "common sense evidence", on qualitative observations not submitted to any analysis or control.

That is the reason we think that a conceptual change is not possible without a methodological change in the way of treating problems. In fact, the common sense paradigm could only be overhelmed thanks to a new methodology which puts together the creativity of divergent thinking and the rigour of hypotheses verified by experiments under controlled conditions. This methodological change, as we know, was not at all an easy one, and it is quite logical to think that the same will happen with pupils.

But, why do not the proposals of conceptual change pay attention to the methodological aspects? In our opinion that would prove that science teaching continues to be centered on declarative knowledge (knowing "what") and forgets the procedural type (knowing "how"). On the other hand, this omission is inconsistent with the proposal of approaching science learning to the construction of scientific knowledge. As Saltiel and Viennot (1985) pointed out, there is not a stage in the historical development of mechanics ideas which fits "point by point" the intuitive pupils' conceptions: the main similitude lies in the difficulties that both must face. And these difficulties are, above all, of methodological nature. In a recent paper, Hashweh (1986), has sustained very similar thesis, speaking of what he calls "commonsense epistemology and methodology" with a very close sense to what we have called methodology of superficiality.

It seems essential, then, to take into account the links between commonsense ideas and commonsense methodology, or, in other words, to stress the necessity of associating the conceptual change to a methodological one, in order to make possible the construction of scientific knowledge, that is to say, the significative science learning.

5. WHAT TO DO ABOUT SCIENCE MISCONCEPTIONS AND COMMONSENSE METHODOLOGY

After what we have been discussing in the previous secciona, we could summarize by saying that there is not much to do about science misconceptions...if we do not take into account, at the same time, the associated commonsense methodology (Hashweh 1986). Only if pupils are repeatedly put into the situation of applaying a "scientific methodology" - that is to say, into situations of identifying and defining problems, putting forward hypotheses, designing experiments and strategies, analysing carefully the results...- they will overcome the methodology of superficiality, making possible the deep conceptual changes which the acquisition of scientific knowledge demands.

We shall now try to justify that physics learning, and more precisely mechanics, can be an ideal way for overcoming the methodology of superficiality. That is, of course, a most important question since, without this methodological change, pupils can not acquire a significative learning of scientific knowledge.

But, why should mechanics be a "golden way" to produce methodological change? and how? The answer to these questions derive from the very meaning of what have called a methodological change:

This implies, first of all, to lose confidence in what seems evident, to doubt about what we belived to be common sense evidence, to start imagining other possibilities -passing from certainty to imagining hypotheses- and, at the same time, trying to contrast the different assumptions in controlled conditions.

But to lose certainty in common sense evidence it is necesary to see that what we considered most certain, can be wrong. It is necesary to see that our ordinary way of thinking can lead to error. And it is very precisely in mechanics where common sense seems to give a most coherent view. That is why the pre-classical paradigm is called "commonsense physics".

It is in mechanics too that pupils have the most coherent and rooted alternative framework. We have already referred (see section 2) to a study we have done consisting of puttting questions to pupils about different preconceptions that have been pointed out in the literature, asking them to express their confidance in the answers. Results show that most of the wrong answers on mechanics are given with high confidance, while this confidance is lower in other domains (electricity, chemistry...). And it is in mechanics where pupils (and teachers!) get most upset when they find out that what they thought was evident, is wrong. Besides, it is in mechanics that preconceptions are less affected by instruction (Carrascosa, 1987) (see fig 2).

This conflict which can lead to the methodological change, is stronger in mechanics than in any other domain: the rise of scientific methodology is historically associated to the study of mechanical movement and mechanics was the first science in the modern sense of the word.

The struggle between the pre-classical paradigm and the new ideas of Galileo, Descartes, Newton,.., is the history of a conceptual and methodological change. This struggle must be reproduced in our pupils, and beforehand, of course, in teachers in training.

Physics and, more precisely mechanics, appear then as a particularly suitable domain to produce the conceptual and methodological change and give pupils the sense of science. Nevertheless, we must signal the danger of trying this methodological change too soon: children need to develop their commonsense strategies of thinking -valid in many situations- just as well as, historically, science revolution was preceeded by a long period of "pre-scientific" work (Gil 1986).

Naturally, to teach mechanics is not enough to produce the methodological change. In fact mechanics has been taught without producing any methodological or conceptual change. The reason can be found in the fact that, as a recent analysis of current problems with school science has shown (Yager and Penick 1983), "most science courses do not include a single experiment where students can identify and define a problem, propose procedures, collect and interpret results or make any decisions".

This situation is quite similar in other countries (Hodson 1985) and it is even worse regarding problem-solving, the other activity that, together with practical work is considered a suitable method to develop scientific skills and attitudes. Research has shown that usual teaching of problem-solving lacks the main characteristics of scientific work: teachers solve problems in a linear way, without looking for alternative strategies and even without any results analysis (Gil and Martinez Torregrosa 1984).

To produce the conceptual and methodological change, we insist, it is necesary to give research characteristics to the learning process, or, in other words, it is necesary to orient the learning process as a construction of knowledge; and that has deep implications in curriculum development. As Driver and Oldham (1986) point out, this means that the curriculum must not be seen "as a *body of knowledge or skills* but the *programme of activities* from which such knowledge or skills can possibly be acquired or constructed". To elaborate these programs of activities is, naturally, a research task.

We would like to finish considering briefly the very serious problem of pupils lack of interest towards science learning (Schibeci 1984; Yager and Penick 1986)

Pupils´ lack of interest in science learning, among other reasons, has led to the development of a integrated science orientation of the curricula (Haggis and Adey 1979), frequently presented as a way of capturing pupils´ interests.

The reasons adduced are well kown and seem quite appealing: it is said, for instead, that there is only one reality and different curriculum subjects break artificially this unity. But, we think that those arguments are wrong because they ignore the nature of science: scientific approach to reality is necesarilly analytic and precise, and different sciences -to which curriculum subjects correspond- have an inner coherence, a structure, which defines the necessary relationship between concepts (Khun 1962), (Host 1978). As Hodson (1985) points out "Because they have different areas of concern and different goals, different sciences utilise different theories and require different sorts of evidence, and so employ different procedures of enquiry."

Each science, each theoretical body of knowledge represents a certain level of approach to reality, which no doubt is a unity, but structured in different levels with their own laws. It is true for example, that all substances are composed by atoms and that physics laws are omnipresent, but they can not give an account of the behaviour of living beings, which is a more complex level, with its own laws. To ignore or to hide this -putting at the same level physical, chemical, biological... approaches to reality, trough their simultaneous treatment- leads to a confused, impoverished and equivocal view of this reality.

Certainly, it is necesary a higher conection between different subjects, showing how , as different sciences develop and deepen, the unity of matter emerges. But that must not lead to a magmatic view, unavoidably confused and superficial, which can have some interest as an initial approach but which it is necesary to break with. Otherwise we shall give a wrong idea of science and stimulate a superficial attitude which is very far away from scientific activity. In other words: The integrated science approach can only stimulate the "methodology of superficiality" and so obstruct the conceptual and methodological change which makes possible -as we have tried to show- both a significative learning and acquisition of scientific skills and attitudes.

On the other hand, integrated science proposals come usually together with the idea of "center of interest" -related to everiday life and so on- as a way of overcoming the lack of interest that the study of "abstract and purely formal" subjects such as mechanics can have for pupils.

This criticism is correct if it refers to the usual way of teaching these subjects, but not if it concerns the subjets themselves: how could it be accepted that the development of mechanics for instance, is an "abstract and purely formal" domain?. reading some of Galileo's texts is surely enough to realize how full of real adventures the development of science is. We can find even persecutions and sentences and, above all, a passionate and passionating struggle against dogmatism, for freedom of thought and knowledge.

The question now is how to recuperate these historical aspects, these science/society interactions, breaking with a long tradition engaged in transforming science teaching in a mere dogmatic transmission of "pure" knowledge. This orientation of science teaching, not only has a high motivation capacity but gives a closer view of scientific development. Moreover it can help to avoid the increasing social rejection of scientific activities, due to environment destruction, arms, race,..

Discussions of the social role of science and scientific neutrality myth, can help to return to science learning the vitality and interest of scientific development itself (Aikenhead 1985).

But science learning can also be, and must be, an adventure in a deeper sense. The adventure of facing up to open problems, finding (or not!) fruitful ways of solution, knowing that one's own thinking resembles that of scientists (including their mistakes!),... In our opinion, although there is still very much to research in this domain, the learning of science oriented as an open and creative activity, with the characteristics of scientific work, can awaken a real and deep interest for science.

So we ratify our support to the model of the learning of science as an oriented research, as a conceptual, methodological... and attitudinal change. A model which is just beginning to emerge but that opens some perspectives in the treatment of science misconceptions together with other important problems of science learning.

FIGURE 1. % of incorrect answers (given with a very high degree of confidence), versus studentes age.

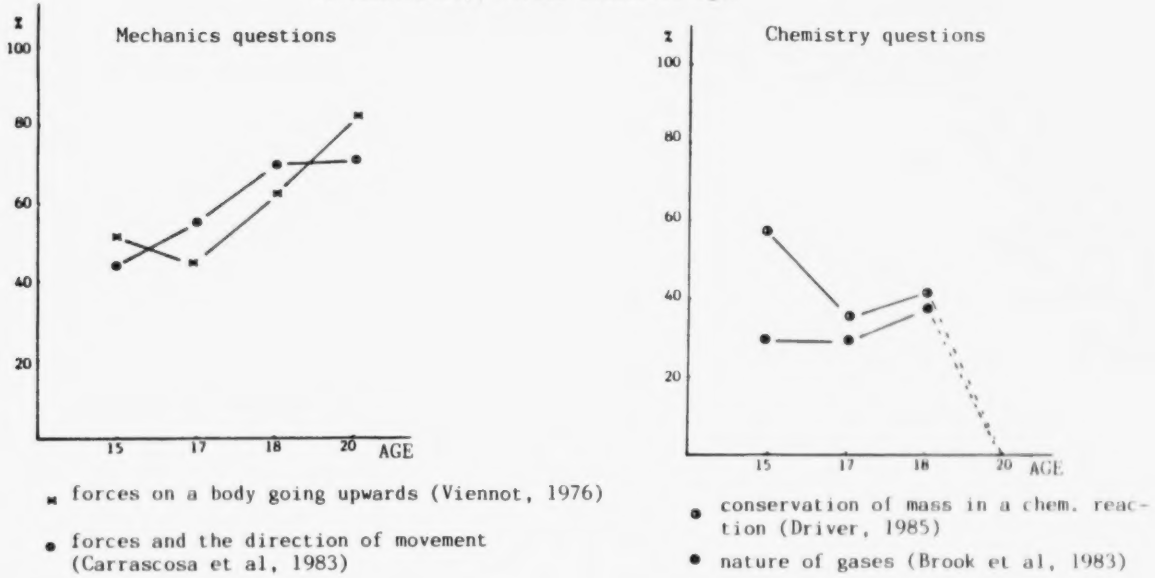
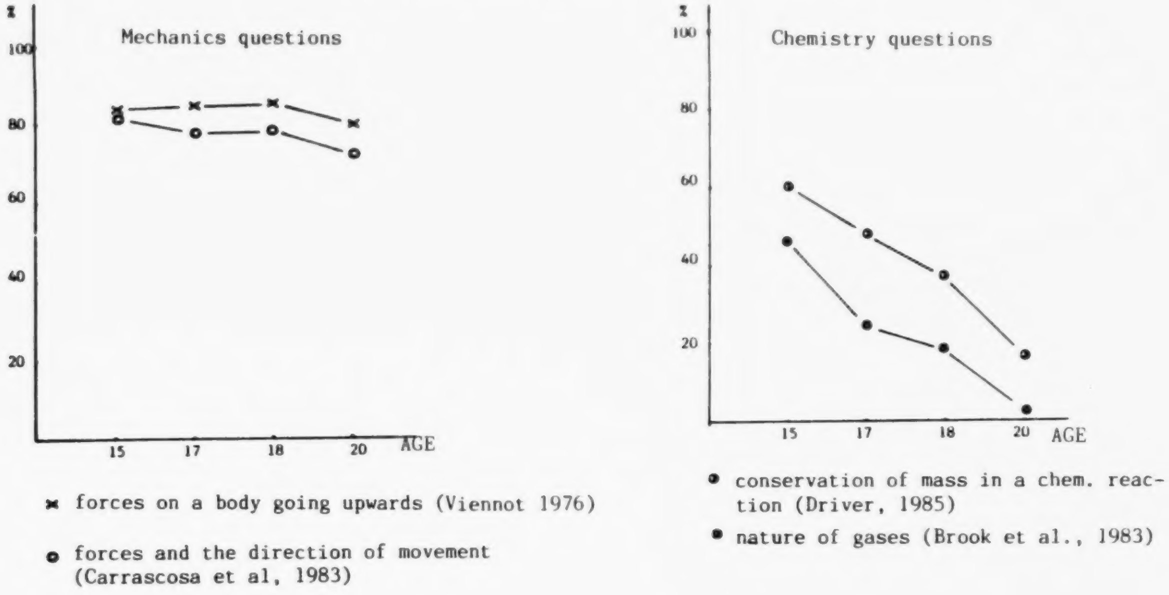


FIGURE 2. % of incorrect answers to questions about well known preconceptions, versus students age



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TEACHING STRATEGIES AND CHILDREN'S SCIENCE: AN EXPERIMENT ON TEACHING ABOUT "HOT AND COLD"

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In this paper we shall describe an experiment carried out by a research group composed by university researchers and school teachers. The aim of the research was to design and try out a teaching strategy based on a constructivist approach to science teaching. A point we would like to stress, because it has been at the base of our research choices, is that the ultimate goal of research in education is to contribute to improving actual teaching in the classroom. Who would deny that? Nobody perhaps. What seems sometimes to be neglected are the implications of such statement: the importance of connecting a specific kind of research, like that about alternative frameworks, with the implementation of teaching strategies on one side and with teacher training on the other.

1. Developing a strategy taking into account pupils' conceptions

This experiment was carried out in a class of 22 Middle School pupils (11-13) who had not received previous formal teaching about thermal phenomena. It started when the pupils were at the end of their first year of Middle School and ended in their third year just before they took their final examination. The total number of hours spent with the class was 36 (9 in the first year, 13 in the second and 15 inthe third). Table 1 shows how the time was divided between experiments and discussion, table 2 shows the kinds of classroom activities carried out in the three years of the experiment.

TABLE 1 & TABLE 2 about here

The teacher of the class, who had collaborated with us also in the past, was a member of the research group. She took part to all the meetings where the experiment was planned, the action to be taken decided and the results discussed. The teacher and one or two researchers from the university carried out the activities in the classroom and were always present during the discussions. The idea was that we were trying out something that could be implemented also by other teachers, our experiment acting as a reference of what could be actually done in the classroom, and the collaboration with the teacher was, in this sense, the fundamental warrant of the possibility to put into practice a new approach to science teaching. The interaction with the teacher should also give us information on the better way to introduce other experienced teachers to our ideas about science teaching based on a constructivist view of learning and suggest possible approaches for pre-service and in-service teacher training.

The research group have been active since many years and several other experiments on developing teaching strategies have been carried out also in the past. In this paper we shall mainly refer to one of them which we shall use as a term of reference in order to discuss the results of the experiment on teaching about "hot and cold". This will prove very useful because the contrast between the two experiments will point out pros and cons of designing structured teaching units compared with a more flexible strategies and will allow to draw some tentative conclusions about the implications for research and teacher training.

1.1 Finding out what pupils think

In the first year our main objective was to find out the principal ideas of the pupils about thermal phenomena which could act as a basis for our teaching strategy. On the ground of the existing literature and of the data obtained in a research work concerning pupils of the same age group

(Foschi, 1984) we prepared a set of four open questions which were submitted to the pupils in May 1984. Also a game where the children were asked to describe the conditions for surviving in the desert was proposed in the same period. The questions concerned thermal equilibrium, conduction, the relationship between heat exchange and temperature variation and were put in a context as familiar as possible to all the pupils and only qualitative answers were asked. One of the questions is shown in figure 1 and the results obtained, organized in the format shown in figure 2, were thoroughly discussed with the pupils.

Figure 1 & Figure 2 about here

The adults played the role of moderating the discussion and never expressed their own opinions but made the pupils clarify theirs own by asking more questions or stressing the differences and the similarities between the ideas of different pupils.

Simone: I meant to say..to object to the answer "the cloth generates heat"...A thing that generates heat is only a living thing.

Adult: You mean that living things only can generate heat, why do you say so?

Simone : because the cloth .. is not something that lives, living...therefore doesn´t generate heat.

Adult: That is something living only can generate heat. So..those who will contribute to the discussion should think about what Simone said.

Vanessa: I don´t agree because I can´t understand why you say such a thing, that you can´t explain. However, as now everyone has his own opinion otherwise and we do not reach any conclusion ever, why don´t we try to take a piece of cloth and put some of these objects inside....so we´ll check what opionion....what hypothesis we made is..is right, that is if what we say is true, ´cause otherwise we shall always have different opinions.

Adult: OK, would you try to be a little more precise about how you would do with this cloth and these things...

(.....)

Silvia: The cloth heats because in my opinion...because the air inside is not changed, there is less air therefore it heats more...the things inside...but the things also take room then there is less air.

Adult: Let me understand: you think that...

Silvia: inside the case there is less air and less air exchange....then it is warmer and then...also the objects, more objects are there less air is there.

Adult: Then the problem is how much air and how much it is exchanged, you say. So in the case it is warmer then outside...thi is an idea we can think about...and to check this what wuold you do?

Silvia: well, I don´t know...

Davide: ...cold things..I don´t agree that "cold things are heated by warm things". For example...I take the iron compass and put it near to the woodden pencil.....I don´t think the copass wil heat up with the pencil because... the pencil...OK it is warm, but it is not very hot.

Adult: That is you say ´if I take a compass which is cold and put it near to a pencil whichis warmer than the copass, they will remain one cold and one warm, the compass and the pencil.

Davide: That´s it...but I noticed once that I kept in my hand a coin, that is also made of iron like the compass, for five minutes, then I felt it and the coin was very very warm....so I thought that the pencil doesn´t heat the compass because it has less temperature whereas the hand, since it has a lot of degrees....I don´t know...36.... heats cold bodies...I thought.

Mauro: I do not agree with Simone because he said that living things only can heat...but, let´s admit that: the radiator isn´t a living thing, but it can heat ..

Adult: and then?

Mauro: then for me he´s wrong because he said that the cloth doesn´t heat, it may be but...that is he said that it doesn´t heat because living things only can heat, and this is not true because the radiator can heat.

(....)

Simone: I wish to answer to some of the questions...that a person, the man, generates heat and perhaps...when he is under a blanket, as she said (looking at a girl who had spoken just before) he sends out heat and it remains inside and the blanket prevents it from escaping, but it also prevents the cold air from getting inside..in fact during the night, if you keep the blanket on, you don´t feel cold.

Vanessa: you didn´t understand anything....

Adult (to Simone): Could you repeat organizing your thoughts better?

Simone: I go under the blanket, if I stay there for 10 minutes, when I get in I feel cold, because there has been nobody there, after about 10 minutes when I open the blanket I feel that there is something like heat and the cloth keeps the heat ...then..wait a moment...I have a few things more...I object to you....The radiator is stoken like a fire-place...

Monica: but still it isn´t a living thing, have you ever seen a radiator walking or growing?

The content of the discussion confirmed the information we already had about pupils´conceptions about thermal phenomena but made also clear that ideas were much more flexible and interwoven than one could think from the answers to written questions. An example of how we tried to summarise the topics of the discussion is shown in figure 3 (this is one of four questions that we put forward for the pupils to think about in view of the following year activities).

Figure 3 about here

Our plan was that in the same first year we could make the students put forward hypotheses to be checked with experiments devised by the pupils themselves. The reality was that the discussion took all the available time and presented us with a huge quantity of information, very rich and very interesting but also very difficult to handle. Seven hours of discussion with the pupils meant more than twenty hours of discussion among the research group, trying to find how the pupils ideas could be made coagulate around some specific concepts, wandering whether this was actually possible or desirable. The attempts at limitating the field of the contributions during the discussion or at making at least all the pupils answer to a common question (for example: what can heat what? and how?) or at having the pupils carrying out little experiments to check their opinions, did not have the desired effects mainly because our disciplinary reference was too far from the pupils´ones and the points suggested for convergence where essentialy those we would choose. Most of them did not even see the need for convergency, they saw the need for deciding about controverse positions among the pupils but could not devise probating experiments to do so.

On the pupils the discussion had the main effect of making them less sure of their answers (and wander also whether we adults know the right answer or not!) and making them realize that the problem was a lot more complex than they thought at the beginning.

On the teacher this long discussion had a rather devastating effect. Never had so much time been devoted to a discussion that at times seemed to have neither rhyme nor reason.It seemed difficult to her to tell whether they had gained anything from it mainly because not all the pupils had taken part in the discussion. She stressed the importance of making experiments, so that all pupils could follow what was going on without getting lost into a discussion. She thought that the position of the adults had been too neutral and that a covergence towards useful ideas should be seeked with more decision.

The university researchers where inclined to underline all the elements they thought may act as a basis for future understanding, whereas the teacher had much more difficulty in reading between lines and was inclined to think that such a long discussion was a waste of time.

> Catia: OK, the radiator....it heats the environment, but there are places where...here near to the radiator, as Mauro said I seem to remember, it´s warmer...but I would like to say something different, for example it is the warm air that attracts the other, the cold one e makes it become a little warmer than it is....near to the radiator; but if someone, for example, after going to bed leaves the blanket open, afterwards, the air that ´s there, that is not as warm as that in the bed, circulates and getting into contact with the warm one makes it colder, that is here is the cold air that has an influence on the warm air.

In a rather confused talk like the one above, we can detect interesting elements of the pupils ideas about the interaction between warm and cold air: the important role played by convection that allows the "different" airs to get into contact and therefore to exchange heat, the fact that there are times when the warm air heats the colder and other when the warm is cooled by the colder.

It is important to point out that the disciplinary knowledge is fundamental in order to perform a detailed analysis of the pupils talk, searching for important elements of their ways to look at phenomena.

1.2 Making pupils do experiments at their choice

However different the positions in the research group, we all agreed that we needed to think about Physics as a discipline on one side and pupils ideas on the other in order to choose among all possible approaches. In the choice also the teaching experience of the upper secondary school teacher who participate in the research had some influence, particularly in pointing out the negative results of a premature approach based on microscopic models of matter. This led us to decide that we wanted to tackle the problem of thermal equilibrium and to develop the concept of temperature, leaving aside, for the moment, the concept of heat which seemed less likely to be managed correctly at this age level implying in some way the concept of internal energy.

We also agreed that new experimental evidence was needed in order to make new data available to the pupils to think about. One thing that had striken us was that no pupil had ever mentioned thermometers during the discussion, although they obviously know them, at least the clinical ones. In the second year we started by giving them thermometers, both bulb thermometers and liquid cristal ones, letting them free to use them for whatever purpose they could find. The pupils were divided into groups of about four and each group was asked to choose a problem they would like to solve by performing experiments. Other materials they had within reach were small bars in wood, alluminium, iron and styrofoam and containers with wood alluminium and iron powder, cold and hot water (and they could ask for anything else they needed).

The problems they chose to tackle were essentially of two kinds:

- to compare the temperatures of objects made of different materials put in different environments;
- to find out what happens when something hot comes into contact with something cold.

The role of the adults at this stage was twofold:

- to participate into the discussions that went on before, during and after the experiments, trying to help the pupils to organize their ideas, giving suggestions more about the method to follow than about the physics content of the experiments;

- to observe the children's behaviours very carefully and to note them down (at this stage four or five adults were present in the classroom).

At the end of this stage (6 hours) there was a general discussion, in which we tried to collect all the problems each group had found and to show that some of them were probably common to all groups although they had come up in different circumstances. We quote below the statements in which the pupils summarized the main problems that arose from the experiments:

- how do the heating and cooling times vary according to the different materials

- how do they depend upon the difference between the temperature of the object and that of the environment

- how the nature of two liquids at different temperature affects the time required to reach the final temperature when they are mixed

- what is the role of the quantity of substance involved

- what is there that has an influence on the temperature of the objects, besides the environment

Although the problems chosen by the pupils had many points in common, from the point of view of the Physics involved, it became clear from the very beginning that there were many different ways to look at them and the groups often failed to recognize when they were tackling the same problem.

Pupils were also asked to write an individual report of he activities of the group they were in. Some common questions to be answered in the report were given to the pupils (i.e. "Which hypotheses did you make in tackling the problem?", "Did the results surprise you? Were they satisfying?", "Did doubts or problems come out during the experiments?").

What seemed to us very dangerous at this stage was that the pupils, being unable to handle all the variables involved in the experiments they were performing, gathered data which depended upon the specific arrangement they had made but gave them a much more general meaning. It appeared that without external help they had no criteria for selecting information other than their own conceptions. They were in danger of either exchanging their previous ideas with much less sensible ones or, even more likely, confirming their own conceptions and making them even stronger because supported by experimental data.

An example is given by the story of the idea, that is very common in children of this age, that coldness and hotness are two distinct entities and that to say that the warmer object heats the colder one it is basically different from saying that the colder cools the warmer (see figure 3 and Catia's talk quoted above). In their experiments some of the pupils tried to measure the time "that a substance takes to be heated" and the time "that it takes to become cold" and found that they were "different"; neglecting all the other parameters involved in the experiments they confirmed their initial idea that iron was a material that "took more time to be heated and less time to be cooled" if compared with wood. This result that was justifiable on condition that it was related to the specific context of how it had been obtained, was in danger to be generalized and to act as a reinforcement of the spontaneous idea of the pupils.

We realized that to make things clearer we needed an experiment which would emphasize the concepts we wanted the pupils to acquire. We did not want to make use of too simplified experiments where variables are automatically kept under control and which at this stage could seem to the pupils the "right" experiment compared with their "wrong" ones. Therefore instead of a real, but "sterilized, experiment we introduced a "thought experiment", in other words we decided to use a device which is at the same time very useful and almost peculiar of Physics. We led them to think of an ideal situation where all problems of conduction were present but under control, and where no sources of heat (or "cold", as pupils say) were present, to think of the characteristics of the system considered (we wanted to convey the concept of insulated system), to focus their attention on the initial and final temperatures of some objects.

We asked them to think they had some perfectly insulated empty rooms at 30°C and a store where some objects were kept at constant temperature of 20°C. The objects could be moved from the store to any of the room without getting into contact with the outside world. In each room a different object was inserted and we asked to make previsions about the final temperature of each room and of the inserted object according to the different characteristics of the objects. A synthetic picture of the thought experiments is shown in table 3.

Table 3 about here

We did not expect this to be easy for the pupils and our expectations were confirmed: to examine a thought situation was beyond the actual abilities of most of them. Nevertheless it acted as a stimulus for the brighter pupils and even though they probably could not grasp all the Physics involved, it gave them a key to future understanding. For the rest of the class the most useful part of the proposal was the dicussion by which we arrived at the ideal situation, recognizing that everything was strictly interwoven and we were trying to find a thread to disentagle what can be called the skein of concepts.

Adult: ...I was thinking of the two groups with which I worked, not to neglect the others, but they put together some warm and some cold water, they looked at hot and cold putting different materials together, then they put together materials at different temperatures and notice that one increased and the other decreased, at a certain time they had about the same value and then they continued to decrease, that is we had one body problems, two bodies problems, three bodies problem according to what we took into account, problems got interwoven one with the other. Those who worked in the fridge saw this too, they saw the temperature of the pots decrease and the other one increase. Then we also have problems of internal surfaces, comparing the work done by different groups. So we would like now, trying to understand something first, then something else, then something else again, because the situation is so complex, so interwoven that if we don´t....let´s think baout something, sorry but I alwys make home-made examples, did you ever try to disentangle a woollen skein? did you ever make a ball of wool run on the floor, it´s all in a mess afterwards, isn´t it? Then one patiently has to begin by pulling a thread and pass it and pass it again...well, one could say: I don´t care about it, I´ll cut everything...but if you are curious to know how it develops, whether you can succed or not, then you patiently...

Simone: if it is too closely-woven, then I won´t..

Adult: Well, if it is horribly interwoven you say I give up and go to play somewhere else.

Vanessa: what if there are some knots?

Adult: Fine! We could try to loose them .... even if it is very complicated you can think that it´s not necessary to complete ...to disentagle everything; if you only need some of the wool, it is not necessary to disentagle all the skein, may be that ..say half a meter is enough for what we want to do, we´ll have a ball with some knots perhaps but it will be a ball of wool after all.

Davide: but then we have a cardigan ...all with knots..

1.3 Physics vs children´s science: an example

While we were discussing the results of the experiments the pupils had made, a boy put forward an interesting idea that his group had formulated in order to justify that all the objects they observed had the same temperature of the environment:

> Alexandro:....Then we came to the conclusion that the temperature has an influence on the temperature....the environment has an influence...on the object temperature. And about this we formulate this hypothesis: given that the environment has an influence on the variation of temperature of the objects, is there a thermometer that can measure the temperature of the objects only, without the environment?

Later the teacher, talking with a girl of the same group, tried to make clearer what the pupils thought:

> Teacher: We need to understand what we mean by temperature of the object, it seems to me...
> Carla: that is the object in itself....it necessarily has a temperature that is...that is near to that of the environment...
> Teacher: ..yes...
> Carla: Just so, I don´t believe it could have another temperature, because the environment has a great effect, that is it virtually gives the temperature to it.

This seemed to us a patent example of a conflict between children´s idea that different objects have different temperatures according to the substance they are made of, and the experimental data showing that the temperatures measured by the thermometers were all the same. The fact that we had invited them to look at the temperature of the environment and to notice that it was the same as that of the objects, had the unexpected result of leading these pupils to interpret the environment as an external agent that forces the objects to take its temperature ("but they keep having one of their own because I can feel them different when I touch them"). They seem to look at interacting things with an antropomorphic model: they use terms like "to give", "to take", "to have an influence", "to keep" with meanings linked to human interactions instead of the metaphorical meanings peculiar to Physics, they imply an idea of resistance, struggle or impotence.

This episode shows, if further proof was needed, that children make sense of what they see or are been told on the ground of their previuos ideas and that what seems to us the simplest idea, the most obvious conclusion, is always reinterpreted by the pupils, often with stringent logic. The teaching strategies adopted in our school are too often based on the assumption that children should "rapidly" learn new ideas. If we think about learning as a creative process in which the pupil changes his mind about the interpretation of reality, we should not expect it to happen so rapidly, we should perhaps value the fact that pupils appear to stick to their own ideas and are prepared to change them only out of real belief instead of simple "consensus".

1.4 From thought experiments to real experiments

The set of thought experiments left the children with a feeling of dissatisfaction: the Physics content had not come out clearly because the difficulties of following the line of thought had been too high. Discussing about the activities for the third year, the teacher, who is a chemist, admitted that she personally had problems in following the line of thought as it had been proposed to the pupils and she suggested that we could try to make the thought experiments more "real". Following her suggestion and in answer to the demands of the pupils who wanted to "understand better the experiment of the rooms" we decided to start with a step by step discussion of the set of experiments. Each step was illustrated by the teacher with transparencies where the characteristics of the different objects had been made more real by actually drawing them and using different colours for the different materials. The pupils were asked to make previsions about the variation of the temperature of the objects and the temperatures were written on thermometers that were drawn in the appropriate positions.

The fact that they could now "see" the experiments better led them to describe more precisely what was going to happen when a certain object was put into the room. In some way they were happy to make the experiments more real and enriched them with what they thought necessary for understanding and could not be neglected without further discussion. It appeared so that it was almost impossible to them to separate the transitional phase (where, as a pupil pointed out, we could not speak of temperature of the room) from the final state where all temperature had fixed values and that it was not altogether irrelevant to know in which point of the room the object was introduced.

Adult: ...In this room at 30°, we take an object from the store and put it in the room. The object is at 20°. Then what will happen here? The thermometer will take...

Catia: the temperature of the environment.

Adult: 30°..why 30°?

Mauro: no, less than that, because there is also the other that has 20°.

Adult: It came with 20° that little one, it gets into a room where the temperature is 30°, what will happen? The temperature of the whole , in your opinion, what will it be?

Mauro: for me the temperature of the environment decreases

Adult: that is the temperature of the room, 30°?

Catia: it is too little to affect the temperature..

Adult: do you agree?

Roberto: at the beginning it may decrease a little, then...it goes back at the same temperature.

Adult: that is as soon as you put inside the object at 20°...

Roberto: the temperature changes..that of the environment..but then it is reestablished..at 30°.

Mauro: but is it a heated room?

Adult: what do you mean by heated? it is at 30°

Mauro: If the temperature is changed...

Adult: The room is only insulated from the outside, cannot be heated from the outside, it isn´t...hasn´t got a radiator. You do not agree with Roberto, Mauro?..Roberto, would you repeat...

Roberto: As soon as they put the object inside the temperature changes...that of the room..

Adult: for example? give a number..

Roberto: 28°, then it goes back to the temperature it had before

Adult: how does it manage to?

Roberto: How does it manage?

Adult: You seem to think of an intermediate phase in which the temperature of the object and of the room may become less than 30°, but then it goes back. Mauro you seem to disagree, what were you saying?

Mauro: I was saying that if the temperature decreases it remains decreased.

Riccardo: I think that it decreases in that moment then it goes up again because the object is too small.

Catia: but for me the temperature of the environment cannot change...

The discussion became a bridge to the actual experiments which were now planned by the pupils but following a line compatible with the frame of Physics. Some assumptions had to be made in order to perform the experiments in the classroom, some of them were suggested by the pupils, some other by us. The problem of the transitional phase was tackled by measuring the rate of change of the temperatures in different positions in the container that acted as a simulated room. The influence of the position of the object relative to the thermometer in the room was checked by having two thermometers in the room, one near and one far from the object. In performing real experiments they obviously had to cope also with many other problems they had already met in their previous experiments, but what made the difference, for them and for us as well, was that we now had a line of thought in common, equally acceptable from the point of view of Physics and that of the pupils. The calibration of the instruments, the insulation of the "room", the determination of the most suitable temperature conditions, the control of the masses involved in the experiments became problems much more easily handled and solved. In figure 4 we quote an excerpt of the final report of a girl where the transition from the ideal situation to the real experiment is nicely illustrated.

Figure 4 about here

2. Retrieving from the past and striking a balance

During the very many meetings of the research group in which we discussed the results of our work with the pupils while it was still in progress, we often compared this experience with previous ones trying to extrapolate solutions that had worked in other occasions or, on the contrary, emphasizing in what this experience differed from the others. In particular we often compared this experiment with one on teaching about "floating and sinking" which had been carried out with the same teacher in a class of pupils of the same age group.

The experiment consisted in designing and experimenting a teaching unit which aimed at making the pupils understand the concept of specific weight and the relationship that expresses Archimede´s law. A major emphasis was put on the experiments performed by the pupils and in particular on the methodological issues of the experiments proposed. The proposal was the result of the work of a large group in which, together with the university researchers, several Middle school teachers also participated and was therefore based on the teaching experience of the teachers as well as on the research experience of the most of the group: it represented a notable effort to conciliate different experiences and different backgrounds. The result was a path to concepts that we thought could be interesting for the pupils of that age and suitable for conveying the message of Physics. The stucture of the unit, also because it resulted from the mediation of different positions, was rather strictly defined had been almost completely decided before we started to work with the class. Although "locally" flexible (i.e. open to pupils´ suggestions about the "best way" to carry out the experiments) it had at its base a flow chart in which the steps and the links between steps did not allow great changes on the way. The experiments suggested had been previously designed and arranged so as to avoid disturbances from undesirable effects, they had been in some way "sterilized" in order to be certain of the results.

The experiment prooved very satisfying for all the participants: for the pupils who found the work interesting and felt that they were performing the experiments "they" had chosen in order to check "their" ideas, the teacher who felt that the pupils had gained something important from that activity and she personally had learnt a lot that could be useful also with other classes, the researchers who thought, at that time, that something had been developed which could be an example of "good" science teaching.

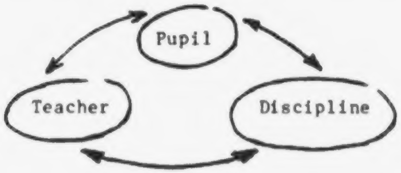
The experiment about hot and cold did not have such "happy" results as the one before. The pupils felt at times disconcerted and were sometimes asked to do too difficult things, in the end they gained a more powerful insight about thermal phenomena but were still left with many doubts and questions. The teacher was probably the one who suffered more and gained less from this experience: for her the previous experience had been very rich in satisfactions and she was not as critical about it as other members of the research group: the new experience had mined her assurance about how to teach science, revealing that perhaps a deeper disciplinary knowledge was needed, certainly a different approach to "right" and "wrong" conclusions and, above all, a different relationship between teacher and pupils had to be developed. The other members of the research group had also moments of depression but felt that a lesson could be learnt from this experience and mainly in the field of educational research this is not something to despise.

3. Some implications for further research

We shall try to summarize in a few statements what we think we learnt. In part they are actually something known which was confirmed, in part they are indications to be tried out in the future:

- it seems that an "initial" period of mess in the classroom is not only inevitable, but even desirable, if we want the pupils to explicit their own ideas and discuss them;
- it appears that without an external (i.e. disciplinary) input the ideas of the pupils are not likely, in most cases, to converge on common conclusions compatible with an accepted interpretation of reality. Yet the line suggested has to be very flexible and the pupils should be let free to interpret it according to their view of the set of phenomena they are trying to describe or explain;
- the role and the nature of the experiments reflect the basic choices of the teaching strategy therefore they may vary according to the different stages of the work: at the beginning they should help the pupils to put forward ideas and the teacher to understand them, later they should interface disciplinary knowledge and children´s science.
- the conceptual change asked of the teacher may prove too difficult for some of them, mainly those who have a long experience of "good" science teaching without having a specific disciplinary training.

We also need to analize more closely the system formed by:



(certainly not an insulated system but in the first approximation let us consider it so)

The teacher should be(or show to be) extremely flexible towards the requests and the proposals that arise from the discussions with the students, giving up the idea that a teaching plan has to be completed in a time rigidly fixed in advance and that immediate results have to be obtained in terms of cognitive development. The processes that can be triggered with a very open strategy like the one described above may be difficult to be known beforehand (beyond every cognitive theory a priori accepted or every model built up a posteriori from phenomenological evidences), and the teacher must be prepared to accept that what he thought had been already acquired has to be rediscussed whenever the pupils, being seriuosly engaged in understanding, feel the need for doing so; above all he/she must be prepared to feel that his/her credibility is sometimes questioned, even if only apparently.

We think that a different relationship between the teacher and the pupil may contribute to establish a good relationship between the pupil and the discipline, both in making the pupil master some aspects of reality about which he managed to build his set of knowledge and in fostering an open and flexible approach towards new and different ideas and in nourishing pupil´s curiosity for natural phenomena.

Also the relationship between the teacher and the discipline has to be modified and can be modified through the different teacher/pupil relationship. It may happen, and it often does, that the disciplinary background of the teacher is put to test by the questions of the pupils and he/she is obliged to make his/her knowledge of the subject matter deeper or, even more demanding, to reorganize it from a different perspective.

Are we just talking abut hopes? There is no doubt that all changes of this kind are difficult but we think that something can be done in order to facilitate the evolution of the approach both of the teachers and the pupils. It seems necessary to design strategies that are a good compromise between a too open strategy, like the one we tried about "hot and cold" that may be too difficult to run by the teacher, and a too structured strategy like the one about "floating and sinking" which could not induce a real change of perspective. The key to the design of such a strategy seems to be again the constuctivist perspective:

- for the pupils we should try to design a path which is obviuosly compatible with Physics as a discipline but which can be interpreted by them in oder to make it compatible with their own view of the world;
- for the teacher we should try to suggest ways of implementing the strategy that are enough detailed but again also flexible so that the teacher could find how to cope with them according to his/her ideas about teaching. In other words we should give them something that they could reinterpret, something that could interface their conceptions of teaching and the one we put forward.

In which ways can the teacher come into contact with our proposals? In which ways can the researchers facilitate the implementation of their proposals? Someone could answer that it is other people´s task to create a channel of communication between the world of research and that of actual school teaching. Our opinion is different. We think that it is our task to invest part of our time for:

- working in the classroom with the pupils (which is also fun) but, more important, opening a continous line of discussion with in-service teachers (which is not always fun);
- publishing research papers where a large space is devoted to the implications for teaching and teacher training, actually giving suggestions for classroom practice which may appear plausible and feasible to the teachers, finding compromises that may seem, only at first look, to lower the level of the research;
- designing specific materials by translating our research works into proposals that can actually be implemented in the classroom.

One last question about teacher training: Why so much trouble "afterwards" when it is possible to save time "before"? The problem of pre-service training is too often overlooked.

This may not be the right place to discuss this topic thoroughly, but we suggest to discuss during this Seminar the first step at least: how to create an interface between psychological and disciplinary knowledge.

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TABLE 1

CLASSROOM ACTIVITIES: SCHEDULE

PERIOD OF THE YEAR	TOTAL HOURS	ACTIVITIES Experiments	ACTIVITIES Discussion
MAY-JUNE '84 (1st class)	9	2*	7
APRIL-JUNE '95 (2nd class)	13	7	6
MARCH-APRIL '86 (3rd class)	15	7	8
	36**		

* Written task and game

** 36 hours correspond to 12 weeks of the scholastic year

TABLE 2

CLASSROOM ACTIVITIES: DETAILED LIST

- Written task	1st year
- Game	
- Discussion of the pupils' answers	
- Thinking about the discussion	
- Introduction of measurement devices	2nd year
- Pointing out problems	
- Experiments in small groups	
- Discussion of main problems	
- Individual written report	
- Thought experiments	
- Written task	
- Discussion of the thought experiments (previsions)	3rd year
- Experiments to check previsions	
- Revision of the experiments	
- Discussion of experimental data	
- Final discussion	

NOTICE: All the discussions were tape recorded

TABLE 3

The store contains 4 objects:

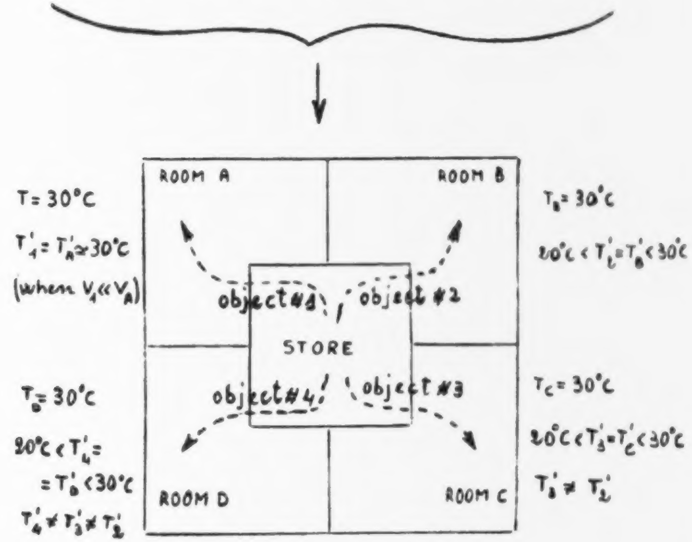
# 1 V_1 ; (M_1) ; material a

# 2 V_2 ; $(M_2 \gg M_1)$; material a

# 3 $V_3 = V_2$; $(M_3 \neq M_2)$; material b

# 4 $M_4 = M_2$; $(V_4 \neq V_2)$; material b

The store temperature is $T_0 = 20°C$


ROOM A
ROOM B
ROOM C
ROOM D
STORE
object #1
object #2
object #3
object #4
$T = 30°C$
$T'_1 = T'_A \simeq 30°C$
(when $V_1 \ll V_A$)
$T_B = 30°C$
$20°C < T'_2 = T'_B < 30°C$
$T_D = 30°C$
$20°C < T'_4 =$
$= T'_D < 30°C$
$T'_4 \neq T'_3 \neq T'_2$
$T_C = 30°C$
$20°C < T'_3 = T'_C < 30°C$
$T'_3 \neq T'_2$

ROOM A → ROOM B : role of the volume

ROOM B → ROOM C : role of the material

ROOM C → ROOM D : role of the mass and the material

On a table, in the middle of a room, there are these objects: a pen, a little knife, a rubber, a marble, compasses, a paper handkerchief, a cloth case.

Do you think there are warmer and colder objects or do you think they are all the same?

Explain your answer.

....

....

We now put all the other objects inside the cloth case.

After some hours do you think there will be warmer and colder ojects or do you think they will be all the same?

Explain your answer.

....

....

FIGURE 1

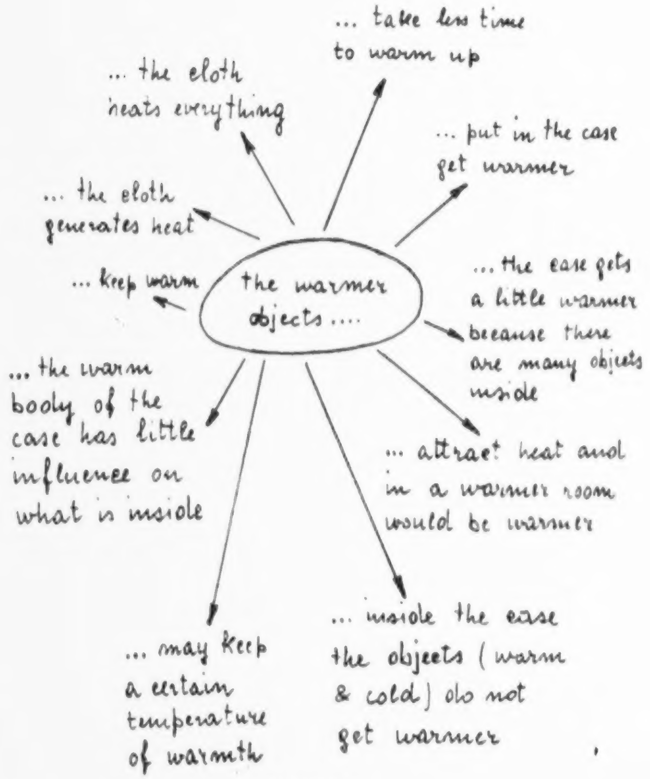

the warmer objects ....
... take less time to warm up
... the cloth heats everything
... put in the case get warmer
... the cloth generates heat
... keep warm
... the case gets a little warmer because there are many objects inside
... the warm body of the case has little influence on what is inside
... attract heat and in a warmer room would be warmer
... may keep a certain temperature of warmth
... inside the case the objects (warm & cold) do not get warmer

FIGURE 2

Someone said: "the warmth in the cold is consumed (consumes itself)"

Someone said: "the warm air becomes cold when gets into contact with cold air"

Someone said: "it's easier for something warm to warm something cold than for something cold to cool something warm"

Someone said: "mixing two equal quantities of water, one hot and one cold, one gets water at a medium temperature"

Questions: If it is true that something cold near something hot gets warm, what does it happen to something hot when it is put near somethimg cold?
Can we say that in the end the two are equally warm?

FIGURE 3

B) Let's consider in the room B), equal to the other, a cube of the same material of the previous one, but bigger and let's see what happens, in order to check our initial hypothesis.

We wish to carry out an experiment like the previous one, making only the size of the bottle larger. But now a problem comes up: the new bottle (that contains water at 20 , instead of 30 of the surrounding water) cannot be all contained in the styrofoam container, if we put it standing. Two opinions are then formulated by the class: someone would incline the bottle, someone else suggests to change the container. Shall we get the same results? We shall see from the experiments that we decided to carry out according to the two different arrangements.

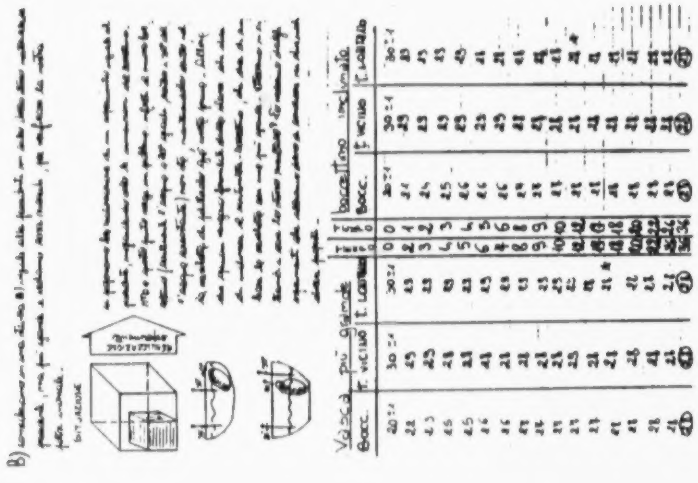


FIGURE 4

ACHIEVING LONG-TERM CONCEPTUAL CHANGE USING THE LEARNER'S PRIOR KNOWLEDGE AND A NOVEL TEACHING SETTING

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INTRODUCTION

Science teaching at the primary level in Western Australia tends to de-emphasise the transmission of content as a major objective. By way of contrast a process-skills approach to teaching has resulted in teachers exploring those classroom and outdoor experiences which might best encourage children to learn through exercising such skills as observing, recording, classifying and inferring [see Western Australian Science Handbook K-7, 1984]. This approach embraces the philosophy that process skills will serve as more suitable vehicles for the learner to understand conceptual material at an appropriate level via activity-centred science.

The last 15 years have seen many science educators identifying and documenting children's views of their world [Pfundt and Druit, 1985; Osborne and Freyberg, 1985; Driver *et al*., 1985] and how these views mediate in the learning process [Happs, 1983; Osborne and Wittrock, 1983; West and Pines, 1985].

Endeavours for bringing about conceptual change have been shown to be both complex in interpretation and unpredictable in outcome (Happs, 1985 [a]) as an individual's prior knowledge and beliefs interact with selected incoming information.

The need to seriously consider the learner's prior knowledge (and associated misconceptions) and to design teaching strategies which allow students to make these explicit, is now being taken into account.

> "The first crucial step in an instructional strategy for facilitating accommodation should be making every student aware of his own pre-conceptions."
>
> [Nussbaum and Novick, 1982, p187]

It appears that a deliberate attempt to promote the exposure of such prior knowledge is advocated so that once revealed this can be "publicly" discussed and analysed to make learners more aware of any initial difficulties.

Nussbaum and Novick (1982) developed a teaching strategy based upon the premise that learning might best be achieved by:

(i) exposing the learner's alternative frameworks (often embedded within their prior knowledge);

(ii) creating conceptual conflict;

(iii) encouraging cognitive accommodation.

Hewson (1982) considered a model of conceptual change and required teaching strategies in terms of student's perception of the offered (by the teacher) scientific framework; The learner being called upon to consider:

(a) the intelligibility of the new (scientific) information, i.e. its internal consistency;

(b) the plausibility of the new information, i.e. is it reconcilable with other existing conceptions?

(c) the fruitfulness of the scientific information, i.e. does it have explanatory power or predictive power?

By considering these attributes the learner may determine the status of his/her prior knowledge and any competing scientific information. Whether or not inappropriate prior knowledge could be modified by having primary school children learn about animal characteristics was a question probed during the investigation reported here.

A PILOT STUDY

Concepts about a variety of animals and their characteristics are taught throughout the primary levels in Western Australian Schools [see the Western Australian Science Syllabus K-7, 1983]. These include central ideas such as: animals vary in size, shape and colour; animals can be grouped and identified by their characteristics; animals have special adaptations which help them to survive.

Primates were selected, by one Year 2 classroom teacher, as representing a group of particular interest in terms of adaptation and resulting characteristics. A small-scale preliminary investigation involved 3 children (aged 6, 8 and 12 years) whose prior knowledge of apes, monkeys and perceived differences were probed by individual interviews. This information, documented in Scherpenzeel and Happs (1986) showed how those children tended to focus on obvious external features such as eyes, ears, tails and arms. These were discussed essentially in terms of size, e.g. "They have big eyes" or "They have long arms" (referring in each case to monkeys).
Similar discussion was forthcoming about apes, e.g. "They have big faces" and "They have big jaws." Perceived differences between apes and monkeys were also discussed in terms of external features such as eye, arm and facial comparisons. This pilot study enabled the investigators to:

(i) gain some insight into some of the prevalent ideas held about apes and monkeys by young children. This information predicted some of the central ideas which emerged from the subsequent whole class study;

(ii) improve their questioning skills on this topic prior to the large-scale investigation;

(iii) give some preliminary thought to essential differences between children's understandings of apes and monkeys and scientific perspectives. This information proved useful when designing appropriate teaching strategies to be used to counter major misconceptions.

THE INVESTIGATION

A class (N = 25) of Year 2 (7 year old) children were taught about general aspects of primates and, more specifically, about differences between monkeys and apes. Two different teaching strategies were used and later compared for their effectiveness. Half of the class (selected at random), were taught in an expository way, whilst the other half was instructed by means of a conflict and accommodation strategy which built upon the learner's prior knowledge concerning apes and monkeys. This "experimental group" was taught by:

(a) exploring their views about apes and monkeys along with any perceived differences;

(b) discussing with them their views about apes and monkeys and how these compared with ideas held by zoo personnel;

(c) providing a novel setting (a morning spent at Perth Zoo) in which learners might best test the usefulness of a scientific understanding of apes and monkeys;

(d) Re-assessing the learner's understanding of ape and monkey characteristics whilst comparing learning outcomes of both expository and experimental groups.

CHILDRENS' PRIOR UNDERSTANDING OF APES AND MONKEYS

Twelve children were randomly assigned to the experimental group and interviewed individually. Each child was shown 16 pictures (9 apes and 7 monkeys) and asked to identify each as an ape or monkey.

Reasons for each selection were sought and recorded on audio-tape for later transcription.
General questions were asked during each interview, along the lines:

> "What do you think monkeys look like usually?

and

> "What else can you tell me about monkeys?"

Similar questions were asked about apes and questioning was directed towards the acquisition of a range of criteria that this group drew upon to differentiate between apes and monkeys.
Nineteen criterial attributes of monkeys and apes were identified and these are summarised below:

MONKEY CHARACTERISTICS	APE CHARACTERISTICS
climb around trees	don't climb around trees [1] (001; 010)
small	bigger than a monkey (002; 004; 005; 007; 008; 010)
long tail	short tail (003; 004; 008; 010; 012;
not hairy	hairy (003)
small hands	big hands (003)
gentle	fierce (009; 012)
longer arms than ape	shorter arms than monkey (002; 003; 004; 007; 008; 010)
small head	big head (003)
small feet	big feet (003)
does lots of tricks	doesn't do tricks (009)
thinner than apes	fatter than monkeys (004)
furry face	no fur on face (011)
have tails	no tails (005)
not as strong as apes	stronger than monkeys (005)
apes and monkeys are the same	(006)
small face	big face (008; 012)
small brain	large brain (007)
long body	round body (007)
long fingers	short fingers (008)

TABLE 1: Differences Between Apes and Monkeys as Documented During Initial interviews

[1] The code 001 refers to the first child interviewed from the experimental group.

It is interesting to note that modal criteria for differentiating between apes and monkeys were:

1. Monkeys are smaller than apes (6 responses)
2. Monkeys have longer arms than apes (6 responses)
3. Monkeys have a longer tail than apes (5 responses)

In addition to this descriptive information about apes and monkeys, the 12 children returned the following scores on the picture identification task:

	CORRECT RESPONSES		CORRECT RESPONSES
001	6	007	0
002	3	008	5
003	6	009	6
004	5	010	3
005	12	011	2
006	5	012	1

TABLE 2. Pre-Test Scores for Children in the Experimental Group

Tables 1 and 2 indicate that one student (005) used a scientifically correct criterion to score 12 (out of 16) correct responses before any teaching strategy was implemented. He had stated (see Table 1) that "Monkeys have tails and apes don't" during the initial interviewing.

THE TEACHING STRATEGIES

The class of 25 children was taken to Perth Zoo one week after the preliminary interviews and the 12 assigned to the experimental group were taught by a Zoo Education Officer who discussed with the group their prior ideas and understandings about apes and monkeys. These ideas were elicited by general discussion (in addition to having been documented during the individual interviews) and summarised on a blackboard.

Alongside the central misconceptions, i.e. those which had support from two or more children, the scientific perspectives on apes and monkeys were written down. These were eventually reduced to 3 observable criteria for differentiating between apes and monkeys as shown:

MONKEYS	APES
1. tail	1. no tail
2. short fingers	2. long fingers
3. stance	3. stance

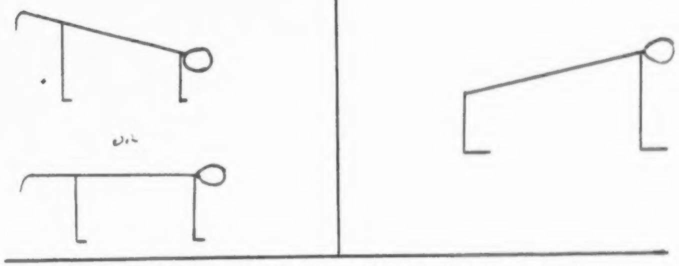

FIGURE 1. Three Observable Criteria for Differentiating Between Apes and Monkeys.

This new information was also given to the children in the form of a worksheet so that they could then move out to the zoo's primate enclosure to identify (under the guidance of the Zoo Education Officer) apes and monkeys in the enclosure.

Most of the time spent at the Zoo by the experimental group was devoted to the observation and identification of primates in the enclosure and in separate cages.
The remaining 13 children (referred to as the expository group) had not been interviewed prior to their visit to Perth Zoo. Whilst the experimental group was being taught in an adjacent classroom, the expository group was taught about primates by the first author. The group was shown overhead transparencies containing information about primates in general and the following specific items of information:

- Primates are mammals, i.e. air breathing; warm-blooded; suckle their young.
- Primates can hold their body upright.
- Primates have eyes at the front of their heads.
- Primates have grasping hands.
- Primates have nails rather than claws.
- Primates have a complex brain.

The above points were discussed at an appropriate level and recorded by the group. Examples of primates likely to be familiar to young children were also provided:

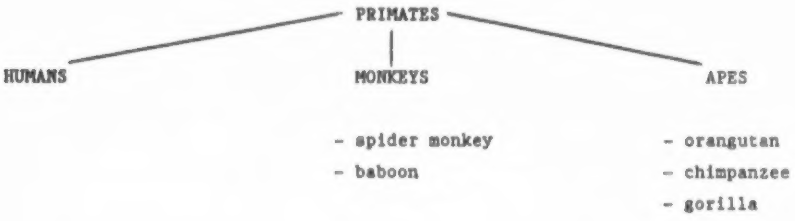

FIGURE 2. Examples of Primates Discussed and Considered to be Known by Young Children

Differences between apes and monkeys were also summarised on overhead transparencies (as shown in Figure 1) and these were noted down by the children.

Finally, pictures of apes and monkeys were shown to children in the expository group and the differences outlined in Figure 1 discussed to facilitate identification of each example.

The children from this group were directed to the primate enclosure and asked to attempt identification of the various apes and monkeys.

POST-TEACHING ASSESSMENT OF THE STRATEGIES

Past studies have demonstrated how the assessment of learning, immediately following a teaching sequence, may not be a true measure of long-term understanding (Happs, 1985 [b]).

In order to better compare possible long-term impacts of the two teaching strategies the 25 children were interviewed individually two months and 10 months following their zoo visit and instruction. As in the initial interviews, the 16 pictures of apes and monkeys were shown to each child for identification and discussion. Comparisons were made between the number of correct responses prior to and following the two teaching strategies for each child and these results for the experimental group are summarised below:

STUDENT	CORRECT RESPONSES (PRE-TEACHING)	CORRECT RESPONSES (2 months after teaching)	CORRECT RESPONSES (10 months after teaching)	CHANGE
001	6 (out of 16)	16	12	-4
002	3	13	10	-3
003	6	16	14	-2
004	5	16	9	-7
005	12	10	12	+2
006	5	16	5	-11
007	0	10	left	--
008	5	16	13	-3
009	6	4	9	+5
010	3	16	15	-1
011	2	10	7	-3
012	1	Abs	6	--
Average	= 4.5	Average = 13	Av = 10	Av = -3

TABLE 3: Comparisons of Correct Scores Before and After Teaching the Experimental Group

Two months following instruction the experimental group, whose prior knowledge was elicited and utilised in the teaching strategy, produced 143 correct responses to primate identification tasks from a possible total of 176. This 81% correct response rate compared favourably with the 31% correct response rate obtained before teaching.

By comparison, the expository group, whose prior knowledge was not sought and to whom the equivalent information about primates was given directly by the teacher, yielded 142 correct responses from a possible total of 208, i.e. a 68% correct response rate.

Ten months following instruction these correct response scores had fallen to 70% for the experimental group and 47% for the expository group.

Comparisons were also made between the success rate of both groups on individual picture identification and these are shown below:

PICTURE	ANIMAL	CORRECT RESPONSE (EXPERIMENTAL GROUP)			CORRECT RESPONSES (EXPOSITORY GROUP)		
		2 mths after teaching	10 mths after teaching	Change	2 mths after teaching	10mths after teaching	Change
1.	APE	60%	72%	+12	38%	50%	+12
2.	APE	100	90	-10	92	75	-17
3.	APE	70	72	+ 2	62	87	+25
4.	MONKEY	90	72	-18	92	37	-55
5.	MONKEY	80	72	- 8	100	37	-63
6.	APE	70	80	+10	62	37	-25
7.	MONKEY	100	81	-19	85	75	-10
8.	MONKEY	50	27	-23	23	25	+ 2
9.	APE	70	63	- 7	77	62	-15
10.	APE	100	72	-18	77	75	- 2
11.	MONKEY	70	45	-25	46	12	-34
12.	MONKEY	80	81	+ 1	77	12	-65
13.	MONKEY	80	81	+ 1	54	12	-42
14.	APE	70	81	+11	62	50	-12
15.	MONKEY	100	63	-37	92	62	-30
16.	APE	90	63	-27	54	37	-17
Success Rate Avge		81%	70%		68%	47%	

TABLE 4: Experimental and Expository Group Performance on Individual Questions About Primate Identification

DISCUSSION

The experimental group was seen to be clearly more successful than the expository group when identifying pictures 1, 7, 8, 10, 11, 13 and 16. Interview data suggested that children from the former group were more aware of criteria for distinguishing between apes and monkeys besides the presence or absence of a tail. Thus in pictures 1, 8, 10, 11 and 16, where the animal's rear was impossible to see (or vaguely outlined) children from the expository group were often unable to make a correct judgement because of their limited knowledge.

K "Monkeys have tails and apes don't"
I "Anything else?"
K "Umm--- I don't remember."
(024)

In contrast, children from the experimental group were generally able to offer alternative criteria for differentiating between apes and monkeys:

C "Monkeys have short fingers and a tail."
I "So Monkeys have got short fingers and a tail?"
C "Yes and it stands straight" (traces horizontal
back with finger.")
(002)

Little difference emerged between the accuracy of both groups in identifying pictures 2, 3, 6, 12, 14 and 15 although the experimental group performed slightly better on each question. Interview data suggested that several from the expository group appeared to have guessed some of their correct responses. In the case of picture 3, for instance, where an ape was facing foward in a sitting position, 70% of the experiental group identified the animal correctly by using the "long fingers" criterion. By comparison, several respondents from the expository group (62% having identified the animal as being an ape) stated that "It just looks like an ape", with no scientific criteria being offered.

A majority of children from the experimental group was able to recall and use the 3 criteria and 6 from this group (003; 001; 004; 010; 008; 006) correctly identified all of the pictures using at least one of the criteria. In contrast, none of the expositiory group was able to achieve this and it became evident that prior knowledge was often retrieved and used incorrectly by children in the expository group:

C "It's a monkey of course."
I "Why do you say "of course"?
C "Because it has a long tail."

and

"That's a monkey because I can tell
by its long arms." (014)

Interestingly, not all of the pictures were identified by the experimental group via scientific criteria and it appeared that in the cases of questions 4, 5 and 9 the expository group was more successful. Responses to Picture 5 (a monkey standing on all fours) suggested that the experimental group had better learned the "stance" criterion since several children ignored the obvious tail and misinterpreted a negligible upwards slope on the animal's back as being representative of an ape's stance.

Ironically, several children from the expository group "identified" picture 9 (a forward facing ape) correctly by reverting back to their prior knowledge of apes as appearing "hairy", "large" or "fierce".

Clear instances of conflict were seen between prior knowledge (misconceptions) about apes and monkeys and the new scientific criteria during the final interview and classification test. It became apparent that many of the expository group members identified the animals using their pre-instructional criteria, often whilst acknowledging their knowledge of some scientific criteria. In one instance Damien readily related how "Apes have long fingers" and then incorrectly classified picture 6 as being a monkey because:

"Monkeys go in trees and that
--- and sit on branches."
(013)

SUMMARY

The results briefly discussed here suggest that some improvement in children's "long-term" understanding about apes and monkeys was achieved by using a teaching strategy that considered the learner's prior knowledge in this area.
The clear regression that took place over the ten month period following instruction suggests that many of the cognitive gains achieved during teaching may well be countered by the impact of the learner's prior knowledge on new incoming information.
Conceptual change appears difficult to bring about in learners at any educational level and this has been discussed in terms of the complexity of the classroom scene which contains many barriers to learning (Happs 1985 [b]).
This investigation attempted to focus on the learner's prior knowledge as a key element in learning. The identification of aspects of prior knowledge about primates along with the discussion and comparison of such understanding with scientific perspectives appeared useful in terms of improving some childrens' long-term understanding. However, a word of caution should perhaps be expressed here since our limited understanding of the many factors which impinge on the learning process must leave a number of questions unanswered in terms of outcomes in this inveaigation. The following points are likely to need further consideration:

(i) Had the expository group been specifically directed towards the primate enclosure rather than the suggestion being made then the investigation might have found a further factor which could have had a significant impact on learning outcomes.

(ii) The use of two teachers at the zoo may well have contributed to the different outcomes from the two teaching strategies despite the teacher of the expository group reflecting that the direct teaching approach had been well received and apparently successful. This judgement was based upon responses to follow-up questions in open-group discussion during the teaching session about primates.

(iii) Only the experimental group was interviewed (individually) prior to teaching and the impact of such interviewing, in terms of cueing or encouraging children to seek out relevant information, is difficult to assess.

In addition to those cited above, many more mediating factors are likely to exist in the teaching-learning environment. The difficulties in identifying and addressing such factors become apparent whenever researchers attempt to understand students' misconceptions and ways to improve learning outcomes. What also becomes evident from this kind of work is the failure of one specific teaching strategy to promote the required understanding in all learners and this difficulty is likely to remain. Thus the classroom teacher needs to be aware of and equipped to utilise a variety of strategies which will better challenge the different misconceptions held by students.

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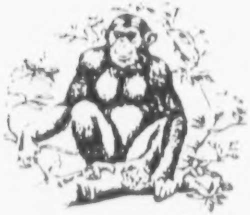
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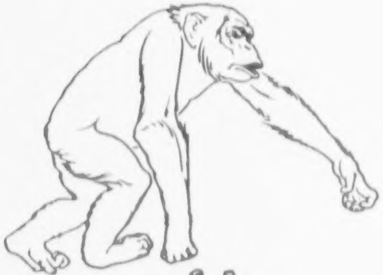
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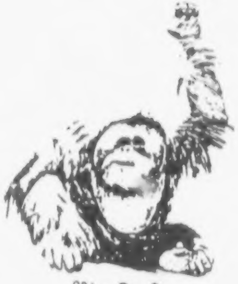
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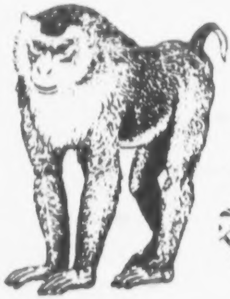
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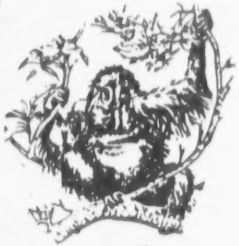
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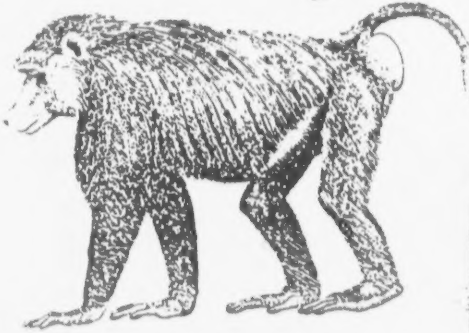
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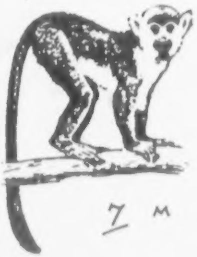
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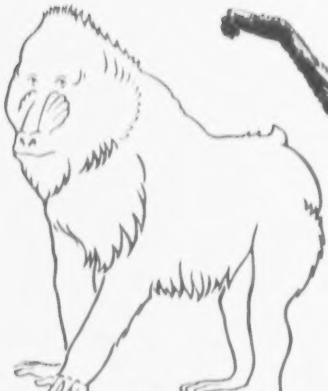

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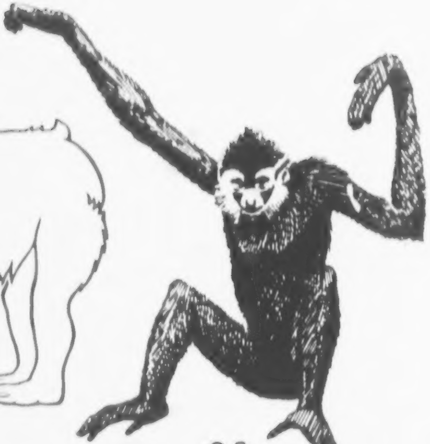

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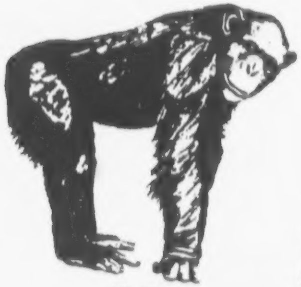

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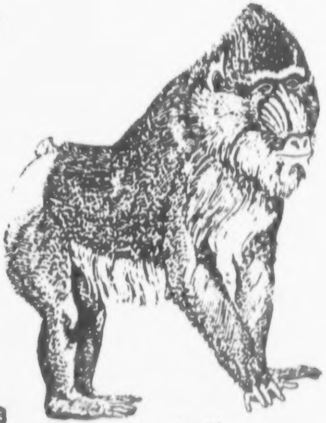

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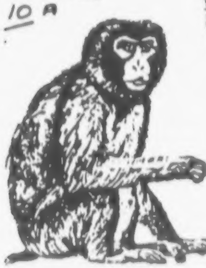

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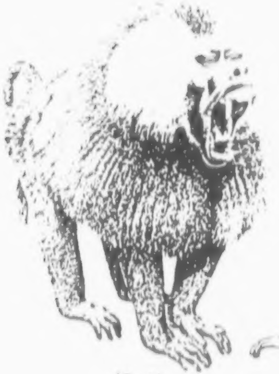

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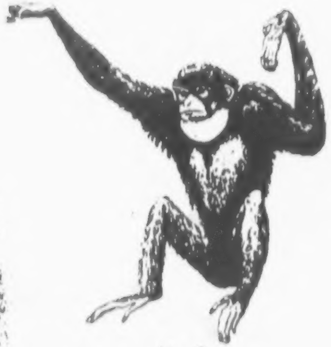

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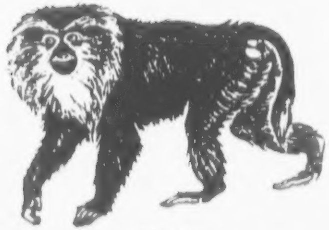

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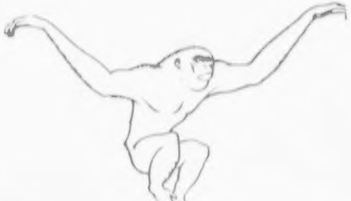

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IDENTIFYING CONCEPTIONS OF TEACHING SCIENCE

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INTRODUCTION

The thoughts that teachers have about the content and students they are to teach influences the way in which they will teach (Clark and Peterson, 1986). This idea, which accords with common sense and common experience, and is also supported by a growing body of research, lies at the heart of our research, of which the study reported in this paper is a part. The argument is as follows: if we want to improve science teaching (and national reports are calling for just that), and if science teaching depends on teacher thinking, and if science teacher thinking can be influenced by science teacher education, then we need to do research on science teacher certification programs. An important component of such research is the tracking of thoughts that student teachers have about content, how students learn, and how teachers teach, in order to allow questions such as the following to be answered. What thoughts change during certification and induction programs? What thoughts most influence a teacher's teaching? Can teacher education programs be designed which will lead to desirable changes in those thoughts which most influence teaching? This argument demonstrates the importance of the study reported in this paper: the development of a task to identify teachers' conceptions of teaching science.

In the next section of this paper we discuss the task which we have developed to identify conceptions of teaching science. In doing so we first identified the dimensions of conceptions of teaching science which recent research on science learning has shown to be appropriate, and then designed a task which would be sensitive to significant distinctions in those dimensions. The task has been pilot-tested with both pre- and in-service teachers. In the final section of the paper we discuss the scheme which we have developed to analyse the responses which are obtained from the task, and present the results of two analyses.

THE TASK: DESIGN AND USE

A. DESIGN

Conceptions of Teaching Science

The aim of the task is to enable a researcher to identify the conception of teaching science which is held by the respondent. In using the term 'conception of teaching science' we mean the following: it is the set of ideas, understandings, and interpretations of experience concerning the teacher and teaching, the nature and content of science, and the learners and learning, which the teacher uses in making decisions about teaching, both in planning and execution. These include curricular decisions (the nature and form of the content) and instructional decisions (how the content relates to the learners in the instructional setting). The structure of a conception may vary considerably from a relatively amorphous collection of ideas with no strong connections to one which is interrelated and possesses a large measure of internal consistency.

We have elsewhere reviewed the literature in order to identify what an appropriate conception of teaching science is (Hewson and Hewson, 1987). This included components on teaching, on content, on learners and their knowledge, on learning, and on instruction. Our specific conclusions with respect to these components are given below in the discussion of the task items. In general, however, we concluded that science teachers should be able to use their knowledge of the particular content to be taught, the particular students they will be teaching, and effective instructional strategies to plan and perform teaching actions which achieve the intention of helping these students learn the desired content.

Design Criteria

It was decided that the task should attempt to meet, at least, the following design criteria. First, the task should raise, and allow respondents to consider, the components of an appropriate conception of teaching science referred to above. Second, the task should allow respondents to provide a diversity of views about these components, without biasing responses in any particular way. Third, the task should allow respondents to refer to day-to-day classroom events while encouraging them to link these events to ideas by which they could be interpreted.

The Task

The structure of the task is that of an 'interview-about-instances,' a technique developed by Osborne and Gilbert (1980). It is used to explore the concept which a person associates with a particular label, e.g., plant, force, or as in this case, science teaching. Each person interviewed is shown a series of instances, originally line drawings, but in this case, short written extracts, and asked whether in his/her view this is an example of the label or not. If necessary s/he is asked if any further information would be needed to arrive at an answer, and then asked to give the reasons which support that answer. The series of instances is chosen to include not only generally agreed examples of instances and non-instances, but also some which are uncertain or controversial. The complete task is given below in Table I.

The task has a number of desirable features for this project. First, it explicitly provides instances and non-instances of science teaching and learning, both inside and outside the classroom. In other words, it provides a practical, experience-based context for each person's responses. Second, it requires the respondent to focus explicitly on science teaching out of other possible issues which are relevant to the classroom. Third, within this framework it does not prescribe what is important, nor to which aspects attention should be given. In other words, we wanted respondents to be able to contribute their own ideas, and focus on what was important or significant to them. Finally, the interview format allows respondents to be more reflective of their ideas, allowing opportunities for reconsideration of earlier statements in light of later instances.

Three different sets of instances have been prepared, with content drawn from biology, chemistry, and physics. For reasons of space, however, only the chemistry set is included. The protocol for the task and the 10 chemistry instances which comprise the task are given in Table I.

[Table I about here]

It will be helpful to refer to these items in the discussion of the rationale for their design which follows. The summary headings included in the table and used in identifying the items below were not shown to respondents. The format of the discussion is structured around the five components from the analysis of appropriate conceptions of teaching science referred to above, viz., teaching, content, learners and their knowledge, learning, and instruction (Hewson and Hewson, 1987). It is important to note that, while the analysis produced a set of prescriptive conclusions, the task is a purely descriptive instrument. Thus, while it is designed to help people consider the issues raised in the analysis, it is not intended to take a position on them. For each topic the issues raised in the analysis will be given, followed by an identification of the items in which they are reflected.

Teaching

The analysis raised the issues that if science teaching, as one particular form of teaching, consists of tasks and activities are they (1) intended to help particular students learn particular content (which may be knowledge, skills, or attitudes), (2) indicative of the particular content to be learned, and/or (3) expressed so that it is possible for the particular students to learn it?

In most of the items, it is reasonable to infer the teacher's intentions with respect to students learning content. This is, however, not the case in Item 2 (Student watching TV) and Item 9 (Student making muffins). As far as the tasks being indicative of the content, this is the case for all items in a general sense. The specific aspects of the content are, however, not at all explicit in Item 1 (Handing out crystals), Item 4 (College professor and first graders), Item 8 (Student asking question), and Item 9 (Student making muffins). Finally, with respect to activities being appropriate to the students for which they are intended, it is obviously not the case in Item 4 (College professor and first graders).

Content

The analysis raised the following issues with respect to content. To what extent should science teachers know the content, i.e., the phenomena, the methods, and the concepts, principles, theories which constitute the science they are teaching? To what extent should they be able to select topics from the content which do justice to the science they are teaching, and are suitable to their students?

The items were not constructed for the purpose of checking respondents' knowledge of science content, though this knowledge could influence replies they give to items 6 (Teacher questioning student statement) and 8 (Student asking question). The items do, however, raise the issue of the nature of science. Items 1, 7, 8, and 9 all include natural phenomena, and these same items plus item 10 raise the issue of experimentation as a method of investigation. Items 4, 6, and 8 refer to scientific concepts, principles, theories, etc., and items 2, 3, and 5 refer to the application of scientific theories in problem solving, and technology.

Learners and their knowledge

The analysis raised the following issues. Should science teachers know what conceptions their students hold about the topics to be taught, and the extent to which these conceptions are scientifically acceptable or not? Should they know the reasons which their students use to support these conceptions? Should they know which topics their students are likely to find difficult, and why they find them difficult?

The items which raise the possibility of teachers investigating their students' knowledge are items 1 (Handing out crystals), 6 (Teacher questioning student statement), and 8 (Student asking question). The rest of the items focus directly on the desired information rather than student knowledge. The teacher is providing the desired information in items 4 (College professor and first graders), 5 (Teacher describes algorithm), and 10 (Teacher writing self study program); has provided it in items 3 (Students in library doing problems) and 7 (Teacher asks students to label diagram), or is checking to see that students have acquired it in item 7. None of the items directly address the issue of topic difficulty.

Learning

The analysis raised the following issues. Should science teachers be aware of the role played by students' existing knowledge in understanding new material? Should they know about research which suggests that students learn new content by using their existing knowledge in a process of active construction of meaning which can usefully be described as conceptual change involving the capture, exchange, and/or restructuring of existing and new knowledge?

The items which raise the issue of the teacher's awareness of the role of prior knowledge include 1 (Handing out crystals), 4 in a negative sense (College professor and first graders), 6 (Teacher questioning student statement), 8 (Student asks question), and 10 (Teacher writes self-study program). Of these, 6 and 8 also allow opportunities to consider learning as active construction of meaning, and as conceptual change. In addition, all items indirectly raise the question of the nature of the tasks and activities with which students are engaged when they are learning.

Instruction

Finally, the analysis raised the following issues. Should science teachers know about, and be convinced of the need to use, instructional strategies which take into account student's existing conceptions, especially when they conflict with those being taught? More specifically, should they know about and be able to put into effect strategies which diagnose students' conceptions, allow students to clarify their ideas, present desired knowledge, establish a

direct contrast between different views, and allow opportunities for explanation of and application to a range of examples? Should they know that materials designed to give effect to strategies such as these enhance their teaching effectiveness?

In terms of teachers taking account of student knowledge in instruction, the same 5 items considered under learning raise this issue, with 1, 6, and 8 doing so in a positive manner, 4 by obviously denying student knowledge, and 10 indirectly as it affects the planning of instruction. Of these, only 1, 6, and 8 raise the issue of diagnosing students' conceptions and allowing students to clarify ideas. Items 2, 3, 4, 5, 7, and 10 all explicitly refer to presenting desired knowledge. Only items 1 and 6 might indirectly lead to establishing a direct contrast between students' knowledge and presented information. Items 3, 5, 7, 9, and 10 raise the issue of allowing opportunities to apply new knowledge, and items 2, 7, and 10 indirectly are concerned with designing appropriate materials.

B. USE

The task has been used with different groups. An initial version was used with 16 participants in a graduate seminar in science education, most of whom were experienced science teachers. Participants worked in pairs and interviewed one another. These interviews were not tape recorded, but interviewers wrote down interviewees' responses. Minor modifications to the task were made, leading to its final form. At this point the three different science versions were prepared.

The final version has been used with two graduate students, both experienced, certified teachers, with 20 students in the secondary science methods course, and with three students who were doing their student teaching. All interviews were recorded on audio tape and transcribed. Lesson observations of the last three students were also made.

Discussion

A number of points concerning the task emerged from the discussion following its use in the seminar, which were subsequently confirmed in individual discussion with student interviewees. First, the task raised all the issues which it was designed to do. Second, the task allowed a wide range of different opinions to emerge. As a result, it is possible to differentiate between people with respect to significant issues. Third, it was one which respondents felt was significant. They found that it made them think very hard about what was involved in science teaching. The above points do not constitute an evaluation of the task, but do suggest that it is able to meet the design criteria outlined above.

Finally, the task is an intervention technique. Respondents found that they needed to reconsider their answers as they worked through later items, particularly because it illuminated possible conflicts in their own thinking of which they had been unaware. The fact that the task is an intervention is one that needs to be considered. It will obviously make it difficult to attribute the source of changes which might occur between successive interviews. The task does not, however, stress a particular conception of teaching science, so it is plausible that the major effect of the intervention will be to help the person clarify his or her existing views, rather than bringing about major changes in those views. At this point, however, the advantages of the task appear to us to be sufficiently clearcut that we are prepared to accommodate the issue of its influence.

ANALYSIS OF THE TASK: STRUCTURE AND USE

A. STRUCTURE

The aim of an analysis scheme for the task is to provide the researcher with a means of representing the responses obtained from the 'interview-about-instances' task such that it is possible to:

- ensure that all significant aspects of a conception of teaching science have been considered;
- determine the extent to which the components of a teacher's conception of teaching science are consistent with each other;
- compare a teacher's conception of teaching science with appropriate conceptions of teaching science;
- compare a teacher's conception of teaching science with his or her science teaching performance; and
- compare the conceptions of teaching science which are held by two different teachers.

Structure of the Analysis Scheme

The form of the analysis scheme consists of six categories, five of which derive from the components of conceptions of teaching science outlined above and one, preferred instructional techniques, which was included as a result of preliminary analyses of transcripts. The six categories are described in detail below.

1. Nature of Science

This category will include any statement which refers to the content to be taught, the intended object of the teaching, that which the teacher intends the student to learn. The content is science.

There are different aspects of science:

- the natural phenomena which are investigated;

- the methods of investigation used both to produce and to apply knowledge;
- the explanations of phenomena in terms of concepts, principles, theories, etc.;
- the uses to which the knowledge is put including explanation, prediction, application, problems solving, etc; and
- the philosophy within which all these aspects are integrated.

Cutting across these aspects are the different disciplines, e.g., biology, chemistry, physics, etc.

Some examples of students' interview statements in this category are:

"Much of science consists of classification, putting things in boxes;"
"Science is a hands-on type of activity;" and
"Science is what is in textbooks or in schools."

2. Learning

This category will include any statement which refers to learning. There are different aspects to consider. These include:

- learning-as-task (how people learn, the process of learning) which may include behavioral aspects, e.g., reading, summarizing, solving problems, etc., and mental aspects, e.g., knowing, understanding, remembering, thinking, controlling, etc.;
- learning-as-achievement (the product, the outcome, what people have learned) which may include the ways in which the outcome is demonstrated; the type of learning, e.g., propositional, declarative, procedural; and characteristics of what is learned such as permanence, flexibility, and usefulness; and

- a theory of learning which outlines how learning-as-task is linked to learning-as-achievement in the context of other factors (if any).

Some examples of students' interview statements in this category are:

"Learning is repetition;"
"A student can learn from a TV program if he is attentive, concentrating, looking for similarities, differences;" and
"Learning can happen when a student is processing, remembering."

3. Learner Characteristics

This category will include any statement which refers to those characteristics which are likely to influence how and what a person learns. Aspects to consider are:

- the person's knowledge, both cognitive and affective, which may include knowledge of the content, empirical and theoretical; knowledge of the context, including personal, school, and society goals; and personal conceptions of knowledge and learning;
- the person's procedural counterparts of the above knowledge, i.e., knowing how to read, write, enumerate, solve problems, study, etc.;
- the person's approach to the tasks of learning, which may include motivation (intrinsic and extrinsic), behavior and attitude, learning set, surface or deep approaches, etc., all of which are likely to be related to the conceptions of knowledge and learning mentioned above;
- the person's developmental and maturational phase;
- the person's innate capabilities; and
- the context of learning which may include family, school, society, and associated role models.

Some examples of students' interview statements in this category are:

"Good teachers know on what level their students are used to learning;"

"Some content is not in the grasp of some students;"

"The student is motivated to learn when actively involved with the knowledge."

While the focus of this category is different from the previous one, it is obvious that there is a strong relationship between the two. As a result it may often be impossible to place interview statements in one or other of these categories with certainty.

4. Rationale for Instruction

This category will include any statement which refers to the reasons which a person may give for using a particular instructional method. These reasons may be related to:

- the nature of the content as outlined above;
- the learner, his or her characteristics, and learning as outlined above;
- evaluation of the outcomes of instruction;
- the context of instruction, including the setting, whether formal or informal; the constraints, e.g., class size, back-up facilities, weather, season, special events; the curriculum; and society; and
- the teacher's personal expectations, concerns, capabilities, and knowledge.

Some examples of students' interview statements in this category are:

"The teacher should give a quiz so that students get feedback and more repetition;"

"Give students a chance to voice their opinions so that the teacher can get an idea of what they have understood or misunderstood;"

"Bringing specimens around gets students interested."

5. Preferred Instructional Techniques

This category will include any statement which refers to the strategies, techniques, methods, practices which the person would use as being effective in science teaching. These may refer to:

- different phases of teaching, including planning for and preparation of instruction, instructional transactions, and follow-up activities, e.g., homework assignments, evaluation;
- the nature of teacher-student interaction, e.g., agenda control, whether active or passive; and
- the type of instructional technique, e.g., lecture, discussion, lab work, small group work, questioning, etc.

Some examples of students' interview statements in this category are:

"The teacher should show students how to use a heuristic or technique;"

"The teacher should try and create and focus student interest;"

"The teacher should select local examples of flora (regular flowers like a rose or carnation)."

While the focus of this category is different from the previous one, it is obvious that there is a strong relationship between the two. As a result it may often be impossible to place interview statements in one or other of these categories with certainty.

6. Conception of Teaching Science

This category will include any statement which refers to the person's conception of the components of teaching science (outlined in the above five categories) and their interrelationships, e.g., between teaching and learning, between teaching and science, between the nature of science and the characteristics of the learner. It is therefore a category which encompasses the others.

Some examples of students' interview statements in this category are:

> "Effective science teaching occurs when students come to own for themselves and understand information that they didn't have before;"
>
> "Science teaching happens when the teacher relates what is happening to scientific concepts;"
>
> "Effective teachers know their audience, and aim at their level;"
>
> "If students ask themselves questions, you can have learning without teaching;"
>
> "You have to have an audience to be teaching;"
>
> "It is not science teaching if no learning, i.e., no understanding, occurred;"

Issues

Two issues in connection with the analysis scheme are important.

1. The categories are not independent of one another, since they represent components of a conception of teaching science. We therefore expect that there are important relationships which exist between them. The sixth category has been used to include statements which refer to such interrelationships.
2. The categories are broad and, as indicated by the outlines above, there are a number of possible subcategories. The decision to work with broad categories was prompted by three considerations: first, it is not at this stage obvious that a fine grained analysis is necessary in order to compare conceptions of teaching science, second, it is not clear that it is possible to define subcategories with the degree of precision required to allow statements to be unambiguously categorized, and third, the task of categorizing a statement into broad categories is significantly easier as a result. The present scheme, however, can easily be adapted to allow a more fine grained analysis, should this prove to be necessary.

B. USE

Use of the Analysis Scheme

The analysis scheme is used in the following way.

1. The transcript is read and statements which precis the respondent's stated view are recorded. Wherever possible these statements use the spoken words of the respondent in order to ensure that they reflect accurately his or her views.
2. Each statement is then placed within its appropriate category. If a statement applies to more than one category it is placed in both. As can be seen below, the categories in some cases do have overlapping boundaries. Within each category, statements which deal with similar aspects are grouped together.
3. The sets of categorized statements are then used to summarize the responses in each category and overall in order to provide a representation of the respondent's conception of teaching science.
4. These summaries are then in a form which allows the analyses mentioned above to be performed.

Two summaries which result from this analysis technique are presented below. The statements from which these summaries were derived are not included for reasons of space.

Summary 1 - Mr Kelly

Mr Kelly was nearing the end of his student teaching experience when he was interviewed. He did not have a great deal to say about the first three categories. As far as science is concerned, he excluded it from a range of activities, i.e., he said science wasn't present in watching TV shows, baking, etc. He made no statements about its nature. In sum, his remarks suggest the inference that he has a restricted view of science, viz., it is what is in textbooks and the science classroom.

As far as learning and the learner is concerned, he said that learning is repetition, and learning problems may occur because the information presented can be over the learners' heads. He spoke of interaction which, for him, means all instances of the teacher being with students including teacher lecturing to passive students. The purpose of students' questions is to let the teacher know if his teaching had been effective. He made no mention of students' knowledge and skills, either as prerequisites or outcomes. This evidence suggests that he has the view that students learn by reception and repetition.

Mr Kelly had much to say about instruction. His preferred instructional techniques were strongly teacher-centered. He said that teachers should provide background before asking questions, that their questions should be convergent and focussed, that they should set the agenda both inside and outside class, that they should demonstrate techniques, etc. His conception of instruction explicitly included students. He said that students had to be present (cf. view of 'interaction' above), involved, reactive to teacher direction, working at calculations, taking quizzes, etc. All of these, however, were to occur in the context of explicit teacher control of interaction and agenda. His statements about instructional rationale related instruction to student learning in order to provide repetition, feedback, and motivation.

Mr Kelly's statements about teaching science provided some definitions and reiterated some of the features discussed above. In his view, science teaching was not involved in watching nature programs on TV, did not happen when students asked questions, and was not happening during teacher planning and preparation. It did involve direct interaction between teacher and student in which teacher gave information to students, or between student and student when one student knew more than the other. He recognized that class debate would in principle be good science teaching, but realized that he didn't do it.

In summary, Mr Kelly's conception of teaching science clearly includes teacher and student: without one or the other, it cannot be teaching. The roles of both are also clearly outlined: the teacher sets and retains control of the agenda, he is active, and he motivates and directs student activities, while the students listen and follow directions; they do not initiate transactions. These roles are elaborated in his preferred instructional techniques and are consistent with his view of how students learn--by listening, repeating tasks, getting feedback. Finally, the content of instruction does not appear to be an issue.

Summary 2 - Ms Beattie

Ms Beattie was midway through her student teaching experience when she was interviewed. First, with respect to the first category--the nature of science--her only comments were about science skills which included observation, asking questions, and making hypotheses. Following instructions wasn't science, but it was a skill which could be used in science. She made no other statements about its nature.

Ms Beattie made a number of statements about learning. She said that in order to learn, students should ask themselves questions (getting at what is confusing is a first step in figuring it out for themselves), and should participate especially on controversial topics. She said that students can learn from reading a text, and learn best by being engaged and asked for information. With respect to the outcomes of learning, she said that learning is trying to acquire knowledge (whether from teacher, text, TV, etc.), it is memory, and it is being able to do things (follow procedures, etc.) for themselves. With respect to learner characteristics, she said that when students are willing and enjoy the subject, when they ask themselves questions, and when they are astute learners, they will learn science. She also said that the level on which students are able to learn is known and used by good teachers . Overall, her conception of learning is focussed on active participation of the learner, whether self-motivated or teacher directed. She has some concern for different outcomes (both propositional and procedural), but said nothing about the role of prior knowledge in learning.

Ms Beattie focussed on both teacher and student activities in instruction. She said that teachers should try to get across knowledge, talk about doing tasks, cover material (though not, by itself, very effective), and reinforce a topic. She said that teachers should bring specimens around (to get students interested) and on more than one occasion she said that they should ask questions, to engage the class (by doing so, students learn better), and to know if students acquired knowledge. She also said that students should think both about observing things and about the purpose of a lesson, they should engage in carrying out tasks, and they should use uniquely science skills. In sum, instruction for her has the dual purpose of providing access to science knowledge and skills, and of encouraging the active participation of her students.

Finally, her conception of science teaching included different aspects. She was concerned about the relationship between teaching and learning. She said that either teaching or learning could go well or badly (they were independent to some extent), but the teacher did have to connect with the learner. Thus, an astute learner could learn well from poor teaching. If students asked themselves questions, they could learn without teaching. They could also learn from text. On the other hand, one could teach, but if the audience was inappropriate, there'd be no learning. Without the audience, however, there would be no teaching. Also, preparation (writing a self-study program) was not teaching. She was also concerned about effective teaching. She said that effective teachers knew their students and aimed at their level, they tried to anticipate problems which could occur with learning particular topics, they invited students to participate, they engaged them in the task at hand. On the other hand, she said that covering material for a passive audience was teaching, but was not effective. Finally, she made no statement which related teaching to science.

In summary, Ms Beattie's conception of teaching science has a strong student focus. She believes that students learn best when they take an active role, are interested and involved, and participate in learning activities, including reading, asking and answering questions, etc. She sees that learning can happen without teaching, but that it is enhanced with effective teaching. Good teachers think about their students in preparing for teaching, they present material, and involve their students in learning. Finally, the knowledge which students bring with them to instruction did not appear to be significant to her.

Discussion

While the content of the two summaries above is of central importance to our ongoing research, this discussion will be restricted to the task itself and its analysis. The following points are of interest. First, the analysis showed that both people contributed statements in each of the six categories. Thus the task was able to elicit responses over the full range for which it was designed, even though there were many more responses in some categories than others. It is too early to say whether this discrepancy is a function of the task or of the persons interviewed.

Second, in contrast to the above point, within each category not all aspects were considered. For example, neither Mr Kelly nor Ms Beattie stated that the knowledge, skills, etc., brought by students to the classroom were important. Without more experience with the task, we cannot say whether such an omission is significant, or is due to a flaw in the design of the task.

Third, within a given category, the task elicited very different responses. For example, Mr Kelly's conception was that learning consisted of reception and repetition, while Ms Beattie's conception was of active participation in learning tasks. This is in accord with one of our main concerns, i.e., that the task should be able to elicit divergent views of teachers.

Fourth, the nature of the responses clearly demonstrates that the two student teachers were using their conceptions to interpret classroom events. In other words, they restricted themselves neither to the descriptively observational level nor to a theoretical discussion, but continually linked the two.

Fifth, the analysis makes it possible to check for consistency between the different components of a person's conception of teaching science. For example, Mr Kelly's view of learning as reception and repetition fits well with his view of teacher centered instruction. Ms Beattie's strong student focus emerges consistently from her views of how students learn, of how one should instruct, and of what teaching is comprised.

CONCLUSION

In this paper we have outlined a task designed to enable researchers to identify the conception of teaching science held by science teachers, whether pre- or in-service; we have presented a scheme which further enables researchers to analyze and represent the responses obtained from using the task; and we have presented the analyses of the conceptions of teaching science of two pre-service science teachers. The task was designed to allow respondents to consider all components of an appropriate conception of teaching science, to elicit a diversity of views about these components without biasing responses in any particular way, and to refer to day-to-day classroom events while encouraging them to link these events to ideas by which they could be interpreted. Within the limited use so far made of the task and analysis scheme, these design criteria appear to have been met. This suggests that the task and analysis scheme have the potential to be valuable research tools in meeting our goal of improving science teaching.

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TABLE I

INTERVIEW-ABOUT-INSTANCES OF SCIENCE TEACHING

PROTOCOL:

1. In your view, is there science teaching happening here?
2. If you cannot tell, what else would you need to know in order to be able to tell? How would this information tell you? Please give reasons for your answer.
3. If you answered 'yes' or 'no', what tells you that this is the case? Please give reasons for your answer.

ITEMS:

1. Handing out crystals
   Teacher in a middle school at the start of a topic on crystals, asking the class, "What can you tell me about the crystals I've passed around the class?"

2. Student watching TV
   A student at home watching a TV program on chemical plants which produce new plastics from coal.

3. Students in library doing problems
   Two 10th grade students in a library working on a set of vapor pressure problems from the chemistry textbook given for homework.

4. College professor and first graders
   College professor lecturing on molecular orbital theory to a small group of first graders.

5. Teacher describes algorithm
   Teacher in front of 10th grade chemistry class, describing the steps used in the factor-label method of solving mass-mass problems.

6. Teacher questioning student statement
   Teacher reads a 10th grade chemistry student's statement that 'Ideal gases have no volume' and asks, "Were you referring to the gas particles or the gas as a whole?"

7. Teacher asks students to label diagram
   Teacher at end of a demonstration of the electrolysis of water distributes a drawing and asks students to label the apparatus used in the experiment from memory.

8. Student asks question
   Junior high school student in class, watching an experiment on the electrolysis of water which has been going for some time asks the teacher, "Do you think you've got all the oxygen out of there yet?"

9. Student making muffins
   A student at home following a recipe for blueberry muffins.

10. Teacher writing self study program
    A teacher, writing a self-study resource center program at home on using the triple beam balance to measure the weight of an object.

THE COSTS AND BENEFITS OF USING CONCEPTUAL CHANGE TEACHING METHODS: A TEACHER'S PERSPECTIVE

by

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Introduction

The past five years have seen a growing number of research studies detailing the common misconceptions about science that children bring to the science classroom. Ministrell (1985) in mechanics, Hesse (in press) on chemical change, Nussbaum (1985) on the particulate nature of gases, Roth, Smith and Anderson (1983) on photosynthesis, Anderson and Smith (1983) on light and seeing.

An offshoot of this research has been attempts to construct materials and teaching strategies to overcome these misconceptions. This has included direct intervention through training experienced science teachers in the use of these materials and then monitoring the day to day happenings in real classrooms. Such research has been conducted by Anderson and Smith (in press) and Roth (1984).

Anderson and Smith identify two different kinds of knowledge held by effective conceptual change teachers. The first is a knowledge and belief that conceptual change is the way in which students best learn science. The second is the specific knowledge held by teachers of science content, of students and their specific misconceptions and of teaching strategies that can help students abandon their misconceptions.

Whereas Anderson and Smith synthesize and characterize the ideal conceptual change teacher from several research studies reporting successful outcomes using conceptual change methods, Roth follows the development of a single conceptual change teacher over the course of three years. I will give a short summary of the Roth study as a means of illustrating how a successful conceptual change teacher operates.

An Example of Successful Conceptual Change Teaching

Ms. Kain is a fifth grade teacher whose students have dramatically improved their understanding of photosynthesis over a three year span. For example, on the first year posttest only 7% of the students used the goal conception that plants actually get their food by making it through photosynthesis. Students retained their entering misconceptions that fertilizer, water and sunlight were actually plant food ignoring that plants make their own food. Ms. Kain utilized in her teaching what Roth terms a discovery-oriented approach to learning and teaching. Smith and Anderson (in press) have characterized discovery-oriented teachers as those who rely upon numerous activities in their science instruction but avoid telling the students the "correct answer". For example, in year one, Ms. Kain provided many experiences for the students to observe plant growth under several conditions and allowed the students to derive their own theories of photosynthesis. Yet, Ms. Kain did not give out information or evaluate the correctness of student responses. She listened and accepted student explanations. The following discourse is taken from one of her lessons on plant growth.

Teacher: Where do they (plants in dark) get their food?

Bob: Sun isn't everything that makes a plant grow. They've got the dark, the water and they've got the cells inside them that give themselves food. And the dirt gives them food and stuff. So they don't just need the sun to grow. They have other things to help them grow.

Ms. Kain then moved on to another student without commenting upon the errors in Bob's response. In year one, Ms. Kain did not have much success in helping her students replace their naive conceptions with scientific conceptions.

By the third year some 79% of the students answered the question, "What is food for plants?", by correctly referring only to photosynthesis or stating that plants make their own food. On other questions pertaining to photosynthesis students showed similar gains in understanding. In the first year only 2% of the students stated that plants need light to make food. In the third

year 52% of the students correctly stated that plants need light to make food.

What did Ms. Kain do differently in the third year that she was not doing in the first year?

Roth identifies two significant changes in Ms. Kain's approach to learning and teaching. Ms. Kain changed her ways of presenting content and in her ways of confronting student misconceptions.

In year three, Ms. Kain's presentations were characterized by teaching photosynthesis from several different perspectives. At one time photosynthesis was a chemical reaction involving the rearrangement of molecules, in another, photosynthesis was described at the phenomenological level where light, water and air combine inside the plant to make food. Ms. Kain also related photosynthesis to other concepts related to photosynthesis like the scientific definition of food and the purpose of the cotyledon. Students were provided with many opportunities to use their new conceptions of photosynthesis. Transparencies, newspaper articles, drawings and written explanations were common in year three.

In addition to changing her method of presentation, Ms. Kain directly confronted her students' misconceptions. By year three Ms. Kain was aware of her students' persistent misconceptions. She looked for them in her students' explanations and confronted them in open discussions. Rather than merely clarifying student explanations she tried to change the way they were thinking. The following excerpt illustrates how Ms. Kain has changed her ways of handling student explanations. She no longer just accepts any explanation but probes students' responses until a scientific explanation has been given.

Question: Why did the grass plants grow in the dark?

Eric: They all need water, the reason those (in the light) look better is because the sun gives it its color and it also helps make those stay healthy.

T: I want to know why the grass grew in the dark. I don't want to know about.....

Eric: Okay, the cotyledon...helped it for a while.

T: So it needed what?

Eric: Cotyledon and water.

T: Why did it need its cotyledon?

Eric: Because it's the food.

At another time, Ms. Kain directly confronted a student's naive explanation that plants will die in the dark because, "...it looks unhealthy." by tackling the deeper problem dealing with the nature of acceptable scientific explanations.

T: Yeah, that's an observation. Remember that a scientist will go beyond that and explain why you think. Why do you think? She's saying that she thinks it's going to die. Because it looks unhealthy. Let's go beyond that and explain why.

Much of what Ms. Kain is now doing in year three is consistent with what most conceptual change theorists believe is necessary for successful conceptual change teaching. Ms. Kain elicits and challenges student misconceptions, presents content in a manner that emphasizes the goal conceptions and provides students with many opportunities to apply the new conceptions. And, most importantly, since Ms. Kain has used conceptual change teaching methods, her students are learning more science than ever before.

Summary And Direction of This Paper

For a growing body of science educators conceptual change theory and strategies point to a future of improved learning in science. To date, however, this group remains small in comparision to the larger body of teachers using more traditional approaches to teaching science. After reading about the positive experiences of Ms. Kain and her students in year three, the question needs to be raised, "Why don't more science teachers use conceptual change teaching methods?"

There may be several explanations. One may be the newness of conceptual change thinking and the lag-time between origination, research and implementation. Another may be the philosophical recalcitrance of existing science teachers to "anything new". The aging body of science teachers may view conceptual change techinques as just another in a long list of teaching gimmicks that are shelved after the first year. Whatever the reasons, I feel it is important for the research community to understand more fully what conceptual change teaching looks like from a teacher's persective. This paper focuses upon one important aspect of conceptual change teaching: the costs and benefits of conceptual change teaching to the teacher.

This paper is divided into three sections: (a.) a review of an application of conceptual change methods to the teaching of chemical change, (b.) an interview with a colleague who under my direction implemented conceptual change methods for the first time in her Physical Science classroom, and (c.) a summary of the costs and benefits to this teacher of using conceptual change methods in her classroom.

An Approach to Conceptual Change Teaching

Conceptual change teaching is a rubric attached to methods of instruction meant to uncover, elucidate, confront and develop dissatisfaction with naive conceptions while supporting the development and adoption of the scientific conceptions. Conceptual change teaching is derived from a theoretical model of conceptual change outlined by Posner et. al..(1982) This model is summarized below in the form of guidelines for the instructional unit on chemical change:

1. Help students to become aware of their own thinking about chemical changes.
2. Create a dissatisfaction with their own naive explanations.
3. Help students achieve a minimal understanding of the scientific concepts underlying chemical changes.
4. Help the students accept the scientific conception as plausible or reasonable substitute for their own naive concepions.
5. Give students enough practice with the scientific conceptions so they come to see them as applicable across a wide range of chemical phenomena.

A typical format used by researchers who are experimenting with conceptual change teaching involves the following sequence:

1. Student conceptions are diagnosed. Often an exposing event, perhaps a demonstration, is used to elicit the students' entering conceptions. In this stage of instruction students are asked to clarify and debate the merits of their own ideas.
2. Student conceptions are challenged. Many researchers have used a descrepant event. A descrepant event is one that runs counter to predictions made when using a naive conception. At this stage, naive conceptions are confronted and refuted. The scientific conception is presented in a form that satisfies the students' need to explain the descrepant event. The scientific explanation

must be presented in a form that is intelligible and plausible to the student.

3. Students are given numerous opportunities to try out the explanatory power of the scientific conception on other events. This further helps the student challenge the naive conception as most students will be inconsistent in their ability to use the scientific conception. Without this added practice using the scientific conception, many students will revert back to using their more practiced naive conceptions.

Diagnosing Student Conceptions

On the first day of instruction on chemical change, students were asked to respond in writing to a series of questions pertaining to the burning of a wood splint and the heating of a piece of copper foil. Several questions were directed at the students intuitive understanding of the Law of Conservation of Mass. One question asked the student to predict whether the splint and the copper would weigh more, less or the same after being placed in bunsen burner flame. These materials were weighed before and after burning. Students were again asked to restate their theories based upon the results of these weighings. At this time I fill the chalk board with all the different predictions and theories. I label the theories according to the predicitions before and after weighing the products of the reactions. Even though this is pre-instruction, the discussion gets pretty heated with various segments of the class actively defending their theories.

At this stage of instruction, not much is said about the correctness of student responses. Students often want to know, "the right answer". When this occurs, I merely tell my students that their preliminary responses are meant to help me create a lesson plan that will help them learn the new material. I also tell them that for them to learn new material it is important for them to understand where they presently stand on a given issue. In the two years I have tried these demonstrations, the students have always accepted my explanation as a legitimate reason to cooperate in the class activities. I might add here that I try to nurture a certain intellectual safety in my classroom. By that I mean, I treat the students' right and wrong answers with equal respect. I try to let students feel that it isn't important if their answers are right or wrong, but rather, that their input is of value. I make it very clear that mistakes are an accepted aspect of learning new material. This seems to take the pressure off the students and they respond freely.

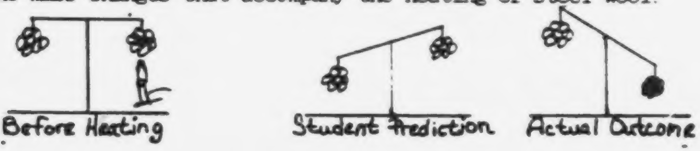
Challenging Naive Conceptions

Next, came instruction on chemical change which focused upon the differences between physical, chemical and nuclear changes, the nature of reactants and products, how the Law of Conservation of Mass impacts chemical changes and the chemist's notion of an acceptable scientific explanation. During this time period the two demonstrations were reviewed. This time, a teacher-led discussion contrasted the naive conceptions with the appropiate scientific conceptions. A chart was prepared for the overhead projector that made explicit these differences. During these discussions it became apparent that several students were uncomfortable with the scientific conception. Ninth grade students are unabashed at telling the teacher exactly where they stand on a given issue. In particular, the notion that an invisible gas (O_2) could actually make the copper gain weight was troublesome.

Two Descrepant Events

An important feature of conceptual change teaching is that after naive conceptions have been identified, there is an attempt to challenge and ultimately discredit the naive conceptions by utilizing a descrepant event. A descrepant event is one whose results run counter to those predicted by the naive conception. Over the past two years, we have used two such demonstrations scheduled a few days apart.

The first demonstration used as a descepant event is the steel wool demonstration. Steel wool is hung on both sides of a balance (see diagram). One side is heated with a bunsen burner. Students are asked to predict and explain the mass changes that accompany the heating of steel wool.



Most of the students predicted that the heated side would weigh less and rise because, "the bunsen burner roached (fried) the steel wool." Many students predicted that part of the iron would be burned away or that the heat would expand the steel wool, making the heated side rise. After the demonstration students were astonished that the heated side weighed more. Several students in disbelief claimed that I somehow rigged the balance. In spite of instruction, many students still overlook the role of oxygen gas in this transformation. For others, it remains incomprehensible that a gas like oxygen could have enough mass to actually make the steel wool weigh more. There were some students, however, who after the demonstration stated that some of the steel wool had chemically reacted with the nitrogen and oxygen in the air. These students were in a minority. Most students had to see (and touch) the nodules of iron (III) oxide before they accepted my proposition that a new substance had been produced. Teacher-led discussions again focused upon the nature of reactants and products in chemical changes.

A few days later students were shown another descrepant event. In this instance students were asked to predict and explain the outcome of burning paper and burning magnesium ribbon. In each instance, the paper and the magnesium were weighed before and after burning. Most students correctly predicted that the remaining ash would weigh less than the original paper. This time several students even suggested that the lost mass was due to the formation of an invisible gas, carbon dioxide. There were, however, many of the ninth grade students who still felt that the paper had been destroyed. A few students related the burning to evaporation.

All the students incorrectly predicted that the remains of burning magnesium ribbon would weigh less than the original ribbon. Again some students accused me of tampering with the electronic balance. At this juncture a few drops of water were added to the magnesium ribbon ash. The students detected the odor of ammonia gas. Discussion focused upon the nature of the products formed in both burnings; carbon dioxide being a gas while magnesium oxide and magnesium nitride are solids.

Following each of these demonstrations, a summary was prepared that contrasted the naive explanations that emerged from the classroom discussions and the scientific explanations that were presented as the goal conceptions for the chapter.

Application of the Scientific Conceptions

In the final stages of instruction, the students were given the opportunity to explain in writing a number of everyday chemical changes. One such exercise asked the students to critique an explanation given by a friend who had not taken any science. In this hypothetical situation, the scientifically naive person states that the ashes left after burning logs in the fireplace weigh less than the original logs because the wood was converted into energy. In another example, the naive person states that the fire made the log evaporate. These proved useful in helping the students extend their ability to apply the scientific conception across a variety of everyday experiences and to contrast the differences between physical and chemical transformations.

The Interview with Mrs. Gast

A Description of Our Working Arrangement

For the past two school years, 1985-1987, Mrs. Gast and myself have applied conceptual change teaching techniques to a module on chemical change that I have written for our ninth grade physical science program. A typical format for this module is as follows. Prior to the actual instruction, I would spend some time explaining the lesson for the day to Mrs. Gast. I would teach two classes of physical science and then meet with Mrs. Gast and describe the outcome of my efforts. She would then try the same procedures with two of her physical science classes. After school we would compare and share our experiences and make plans for the following day's lesson. While I never directly observed Mrs. Gast teaching a lesson, I have every indication that she followed the agreed upon lesson plans.

The following interview is interesting because there is little information in the literature on what happens to conceptual change theory on its way to becoming conceptual change teaching. Mrs. Gast is in no way an expert on learning theory. What she has learned of conceptual change theory has come from our informal discussions after school hours. Thus, her perceptions provide new insights into how a typical teacher might adapt conceptual change techniques to their teaching situatuion. The following is a summary of her perceptions of teaching, learning and the effectiveness of conceptual change techniques to promote understanding rather than rote learning in her students. From this clinical interview several issues emerged that seemed pertinent to application of conceptual change techniques by other teachers.

Mrs. Gast's Perceptions of the Nature of Learning Science

The interview began with my asking Mrs. Gast about the nature of science.

I: In your mind, what are we really trying to accomplish in science? What is it that scientists do that everyday people do not when observing a phenomenon like burning?

Mrs. Gast: Scientists can take, examine....what is happening and ask why it happens....to explain what normal people never think about. Kids should be able to look at a phenomenon and ask what is happening, why is it happening and what can I make of it? I also want then to learn a scientific method...a way of solving life's problems...like

what happens if their kid comes down with a fever, how are they going to handle that?

The above statement suggests that Mrs. Gast holds to some degree that the business of science is to describe, explain, predict and manage the physical environment. Later in the interview she states that her present objective in teaching about the chemistry of burning is for students to, "be able to explain why and how a match burns." In this way she is like Ms. Kain in her third year who emphasized understanding rather than just exposure to new concepts. Mrs. Gast, however, didn't always think about learning in this way. The discussion turns to her old approach to teaching. It is here that she confides that, "last year...I wanted to be the one to say, 'this is the way it is. Learn it. Regurgitate it back and you will get your grade...'" These statements suggest a didactic approach to teaching. Now, however, she wants the students, "to understand the concept we are teaching, rather than just learning a bunch of facts and giving the facts back to us."

I explored her understanding of conceptual change teaching.

I: What does conceptual change teaching mean to you?

Mrs. Gast: To me, conceptual change means that you have a concept in your mind, based upon things you have observed.. ..things you have been told and experienced. Somewhere you have an idea of the way things are. Then you are asked to look at something in a different way and suddenly you realize that everything you believed isn't true...

At another time she stated that, "people, students see and hear things, not the way they are but the way they want to...if what they hear is unpleasant or contrary to their present ways of thinking, they have a tendency to reject it, they don't want to change their thinking...

Mrs. Gast's Approach to Conceptual Change Teaching

I: What do you do as a teacher to overcome this prior knowledge?

Mrs. Gast: You introduce them to an idea. For example, in the steel wool demonstration you have them explain what is going on. You have them develop their hypotheses....you tell them what was wrong with their line of reasoning, but you don't drop it, you build upon it. You have the students look at other chemical reactions....like paper burning and explain why it loses mass. You try to convince them that their concepts are wrong and that they should try another line of thinking.

I: What goes on in your classroom?

Mrs. Gast: Well, if you are a teacher that likes things nice and orderly, you won't like it (conceptual change techniques) because once you get these kids brainstorming.. ..there will be some conflicts (different ideas will emerge)...some will openly say to others that they are all wet.

I: You mean there will be dialogue between students?

Mrs. Gast: (Quite animated at this point) You bet! Dialogue between students ....and teacher and students...it will not be orderly. It will be noisy. If you are a good teacher you will still have control over this, but I also think that part of the learning process is the exchange between students...I want students to be able to listen and to weigh the evidence so they can see where other people come from...

This is interesting because her discussions thus far about her classroom focus upon cooperation and interaction among students. Later in the interview she addresses the issue of misconceptions.

I: What did these revelations from your students mean to you?

Mrs. Gast: They helped point out some of the misconceptions that students have...like burning makes things weigh less. I knew where the kids were coming from because they were relating their responses from the burning of paper to the burning of the steel wool...many were shocked when it (the steel wool) weighed more. A number of times they would say that I tricked them in some way.

This last statement suggests that Mrs. Gast is a conceptual change teacher in that these teachers seek out and have knowledge of their students' misconceptions. There is, however, another aspect of being a conceptual change teacher that doesn't fit Mrs. Gast at this time. That aspect is the belief that learning can only occur when the misconceptions are directly confronted. The conceptual change teacher uses her knowledge of misconceptions to directly attack and show the errors in the misconception. Even though Mrs. Gast acquired knowledge of her students' miconceptions during her classroom presentations, it seems to me that she only half-heartedly utilizes this knowledge in her teaching. Mrs. Gast seems to hold on to the belief that giving her students experiences that challenge the misconception is enough to promote conceptual change. While she has gone well beyond a didactic approach to teaching and tries to provide opportunities for students to acquaint themselves with their own thinking through interactive classroom activities, there remain remnants of her older style of teaching. Several times in the interview, she seems satisfied if the students are "exposed" to different ways of thinking and if students have the opportunity to create their own theories rather than the direct confrontation between competing conceptions. This may be appear to be a minor point but to me it demonstrates that she still has not completed her transition to conceptual change teaching.

The following segment seems to clarify this point. I ask Mrs. Gast about conceptual change methods.

I: Is this a good way to teach?

Mrs. Gast: ...yes, from the standpoint that it makes students think and helps them understand the concepts...

I: What helped you the most?

Mrs. Gast: The demos....they really showed the students the concepts we were trying to teach...

By concepts, Mrs. Gast is referring to the scientific concepts about burning etc.. Mrs. Gast spent some time talking about how conceptual change teaching methods had opened her to a whole new approach of using demonstrations to elicit student interest. I tried to leave an opening for her to discuss the importance of directly confronting the students' misconceptions which she knows exist. Yet, in over two hours of interviews she never once stated that a direct attack on misconceptions is important. In fact, when I direct the interview in that direction, she evades the question.

I: What about the list of misconceptions that I prepared...

Mrs. Gast: I didn't put the kids down for their answers. It was just enough that they were willing to participate and share their ideas. I didn't jump on the kids, I don't want any of my students to think they are stupid.

While I know that Mrs. Gast did address the misconceptions during classtime, I have the notion that the misconceptions were handled as a matter of passing. I am thinking that Mrs. Gast's concern over the sensitivities of her students may have prevented her from confronting the misconceptions. It may well be that her instructional goal was to get student participation, expose the students to the scientific conceptions and leave it to the student to see the error of their ways and adopt the scientific conception.

Mrs. Gast has included the personal element in conceptual change teaching, the bond between teacher and student. In another segment of the interview Mrs. Gast has stated, "I interact more with the students (this year). I know their dispositions, their problems...kids tell me things, they confide in me."

The interview next addressed the issue of the effectiveness of conceptual change strategies in promoting understanding. Mrs. Gast referred to hands-on-activities several times in the interview. I wondered if she had equated conceptual change teaching with these kinds of activities. She told me that she had some previous experiences back in the 70's with an "open lab" science course.

Mrs. Gast: The students worked at their own pace. If they wanted to work they did and if they didn't nothing happened. There was no continuity to the program...the students did their own thing...

I: Do you think these students really learned science from these experiences?

Mrs. Gast: I don't think so...there was no direction...you can't just give experiences and hope they learn....they need to be able to explain why the match is burning.

I: Are hands on activities enough to promote conceptual change...the kind of learning we've talked about?

Mrs. Gast: If the kid is receptive then they might work, but probably not...you will need to do other things.

I: We have addressed their misconceptions straight on by contrasting the naive conceptions with the scientific conceptions...what affect does this approach have on student learning?

Mrs. Gast: It (the contrasting) gets the students to take notice that maybe there are some ideas that they have not considered before. I've had some students tell me that I was all wet. They feel threatened. All of a sudden you are asking them to change ideas that they have had for years, some are just not ready to change and they tell me that.

Classroom Management and Conceptual Change Teaching

In the final portion of the interview, we discussed some of the problems she incurred while implementing conceptual change strategies.

I: Let's talk about your personal experiences as a teacher using conceptual change techniques for the first time. Was it easy or hard for you last year?

Mrs. Gast: Last year it was very hard. This year is much easier. I say, "OK, guys. Take a look, think it over, we'll discuss your ideas, the good and the bad...." The kids like to be a part of the learning process....last year...I felt confused, I knew what I wanted them to learn but I had a whole new role and I had some problems...This year I realize there are some kids that I will never reach, that may seem like a cop-out but it isn't. I would like to reach 100% but I know I can't...some students just won't drop their present ideas.

I: What about the amount of time it took for preparation?

Mrs. Gast: It wasn't so bad the second year, but in the first year I spent hours getting ready....and that was even after you wrote all of the notes and the demonstrations...I could have never done it by myself....I needed your help.

I: What about the kids, the mechanics of teaching in a room full of kids?

Mrs. Gast: A lot depends upon the class. Some allow you to do a lot of demos, have a laid back atmosphere, but it doesn't always work. Kids take advantage of the situation. Some enjoy the banter...the interaction, but others take advantage.

Later, she returns to the topic of classroom management.

Mrs. Gast: I felt in some ways threatened...what if an administrator walked by...they would think there was chaos going on because it is noisy and there is interaction between students...I was also threatened by the thought that one kid, a deep thinker would come up with some idea that may have some validity that I never heard of before...I wouldn't know how to answer him....For a teacher who needs a very structured, very controlled classroom...until they can relax and see that the kids are

learning by interacting...they may be scared off and go back to just teaching the facts.

Mrs. Gast's fear of the smart student is a real one. For a teacher who has a weak academic background can easily lose a class if they have to say, "I don't know", too many times. I asked Mrs. Gast about her own personal knowledge of chemistry.

I: What about your own personal knowledge...rate your own chemical knowledge.

Mrs. Gast: ....before, I never used to think at the atomic-molecular level...I just used to use words like chemicals...you must be more knowledgeable to use these methods and you must not be afraid to say, "I don't know."

I: In terms of your own teaching, how do you feel after two years of trying conceptual change methods?

Mrs. Gast: I'm much more confident, more relaxed...more daring...I'll try demos now that I would never have tried before...I'm much more adventuresome in my teaching...

The interview concludes with a discussion of how conceptual change techniques could be brought into the mainstream of science teaching. It is here we discuss the role of text books.

I: In terms of our text book, if you had used only the text and not the prepared notes on conceptual change, would you have had the personal knowledge of your students you claim to now have?

Mrs. Gast: I don't think so...I'm sure I wouldn't have any knowledge of my students' misconceptions....their ability to reason...

I: What about our text book...

Mrs. Gast: Our text book is too shallow. It hits a topic and two pages later they are off it. They assume the kids know things they don't....(The book says) here are the facts, facts are important but not everything...conceptual change (methods) make students think...

I: Our text book has many chapters. The recent science MEAP-test (a State of Michigan achievement test) covers chemical change and a lot of other topics as well. In our daily chats you have indicated a worry that we are spending too long on some topics. Can you comment upon this in light of conceptual change teaching?

Mrs. Gast: It does bother me....that I wont't have time to teach some important topics that will be covered on the MEAP.....like machines and Newton's Laws of Motion. But, I have found that it takes quite a while for students to really grasp a topic like chemical change.....some won't let go of their misconceptions...

I: Would it be helpful to have a list of the common misconceptions in the text?

Mrs. Gast: Defintely so, if you knew some of the common misconceptions then we would know where to begin to change their (students) thinking...to get them to think scientifically rather than use everyday thinking.

This concludes the interview with Mrs. Gast. The final section of this paper will summarize the key elements of conceptual change teaching derived from a teacher's perspective.

The Costs and Benefits of Conceptual Change Teaching from Mrs. Gast's Perspective

This has been a story of a teacher who is successfully learning to use conceptual change teaching techniques. Let's return to the key question stated in the Introduction, "If conceptual change teaching is so good, why aren't more teachers using these methods?" This section attempts to tease-out of the interview with Mrs. Gast the important aspects of conceptual change teaching as they seem to apply to teachers and teaching in general.

The Costs

The difficulties encountered by Mrs. Gast along the path to her successes reveal some reasons why it may be difficult to implement conceptual change teaching on a large scale.

1. A prior commitment to the kind of teaching that leads to real understanding. For Mrs. Gast, conceptual change methods do lead to an understanding of chemical change rather than rote memorization of the facts. Experience has taught her that traditional text-based and discovery-based approaches keep the students busy but do not promote a scientist's understanding of chemical reactions. Not all

teachers share Mrs. Gast's understanding of the problems that often accompany these other approaches to teaching.

2. Mrs. Gast is learning how to teach for conceptual change under ideal conditions. Few practicing teachers have this opportunity. She has daily help with the organizational and content aspects of teaching. She is regularily coached on how to present the material and knows in advance how her classes might respond in a given situation as her classes followed those who had already been given instruction.

3. There is a demand for a multiple teaching strategies. Within a single class period, Mrs. Gast is asked to shift from open discussion to explaining ideas to application of the scientific concept to new situations.

4. There are concerns over orderly classroom management. Transitions from lecture to demonstration to open discussion can pose problems if there is a lack of cooperation by all students and active engagement by many of the students.

5. There are concerns over the reception of the school administration both to the implementation of "different" teaching methods and to the sometimes boisterous activities associated with an open discussion format. (Fortunately, this teacher has a supportive principal.)

6. The need to admit that many of her students are not learning the material. For some teachers the first time they learn of their students' progress is after the exam has been given. One important aspect of using conceptual change methods is that the teacher can monitor the progress of their students. After spending hours in preparation it can be deflating to find that a large proportion of the students lack an understanding of the important concepts. It takes a while for a teacher to accept the time-lag between instruction and student understanding. Teachers must accept the idea that changing a student's conceptions may not be accomplished in a single class period.

7. The demands upon her own knowledge of the topics being taught and the lack of support from the text book. In Mrs. Gast's case, she had to spend considerable time relearning the topic of chemical change from a conceptual change standpoint. Almost all of the content came from sources other than the text book. Student misconceptions were derived interactively in a classroom setting. To be able to take student responses, derive the underlying misconceptions and address them without the anxiety of "looking dumb" in front of the students puts a great information processing burden and content burden upon the teacher.

8. The work load is increased. Without the benefit of prepared materials, conceptual change teaching can demand many additional hours on top of an already hectic work load. In Mrs. Gast's case, she was given prepared materials and an explanation of how to use them prior to meeting with her classes.

9. Conceptual change teaching because of the depth of understanding it strives to impart takes more classtime to implement. As much as two to three times the classtime was needed to teach the topic of chemical change by conceptual change methods over traditional text oriented methods. This places additional stress on the teacher because the teacher must choose which topics will be taught. This posed a problem for Mrs. Gast as she felt that chemical change was very important yet, the time spent on chemical change was time that could be spent teaching about simple machines-another interesting and important topic.

The Benefits

1. The feeling of professional growth and accomplishment. Mrs. Gast openly admitted that she is, "much more daring" than ever before. She feels that she has control of the course she is teaching and after two years learning conceptual change methods is having fun in the classroom.

2. Student learning is increased. One of the reasons why Mrs. Gast feels good about herself as a teacher is because she has actually monitored student learning from pretest to posttest. While not every student reached the goal conceptions for chemical change, enough did to let her see the fruits of her efforts.

3. The closeness to her students. Mrs. Gast is a wife and a mother of three children. She thinks of her students as part of her extended family. She sincerely cares about her students and wants them to learn science. Conceptual change teaching allows for many interactions between teacher and student where a special chemistry forms close relationships that go beyond a given class period. The process of helping her students over cognitive hurdles puts Mrs. Gast in a position to help them over the more life-oriented hurdles that fill adolescence.

Concluding Statement

All this suggests that for most teachers, as for Mrs. Gast, becoming a conceptual change teacher will be a slow and difficult process-one virtually impossible without a lot of support. The experiences of Mrs. Gast and others, however, suggest that it is possible for practicing teachers to acquire a working knowledge of conceptual change teaching methods. Additionally, Mrs. Gast has shown that conceptual change teaching can lead to rewards that make it worth the effort.

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DAVID HAWKINS, CRITICAL BARRIERS AND THE EDUCATION OF ELEMENTARY SCHOOL SCIENCE TEACHERS

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> 608 Is it wrong for me to be guided in my actions by the propositions of physics? Am I to say I have no good ground for doing so? Isn't this precisely what we call a 'good ground'?
>
> 690 Supposing we met people who did not regard that as a telling reason. Now, how do we imagine this? Instead of the physicist, they consult an oracle. (And for that we consider them primitive.) Is it wrong for them to consult an oracle and be guided by it? -- If we call this "wrong" aren't we using our language-game as a base from which to *combat* theirs?
>
> 610 And are we right or wrong to combat it? Of course there are all sorts of slogans which will be used to support our proceedings.
>
> 611 When two principles really do meet which cannot be reconciled with one another, then each man declares the other a fool and heretic.
>
> 612 I said I would 'combat' the other man, -- but wouldn't I give him *reasons*? Certainly; but how far do they go? At the end of reasons comes *persuasion*. (Think what happens when missionaries convert natives.)
> (L. Wittgenstein, 1969).

Introduction

Over the years the pioneering work of David Hawkins has had a significant and enduring impact on science education particularly at the elementary school level. In this paper we pay particular attention to that portion of his research and writing that centres around critical barriers. In doing so we propose to focus on two closely related strands of his work: first his studies of the nature and origin of critical barriers to learning; and, second, the innovative efforts of he and his colleagues in working with elementary school teachers whose own understanding of science was stymied by these barriers.

Our aim is to consider strategies growing out of a critical appreciation of this work that might ultimately be used in helping elementary teachers to better understand their students and the difficulties they have in learning science.

I. The Theoretical Framework: The Nature and Origin of Critical Barriers

One of the central themes running throughout Hawkins work is the conviction that at all levels science education must be committed to fostering wider public understanding of science. What is absolutely essential to the achievement of such understanding, he maintains, is the requirement that students come to understand certain basic or elementary concepts associated with different fields of scientific inquiry. These concepts are elementary not in the sense that they are easily grasped, but rather in the sense that they serve to organize and structure different fields of scientific inquiry. Unfortunately, Hawkins points out, in teaching science at these elementary levels the scientifically naive or uninitiated almost invariably run afoul of various obstacles to learning and understanding. In their recent work he and his colleagues have paid particular attention to a special class of learning difficulties which they have baptized with the name of "critical barriers". In order to characterize this research and locate it within the broader domain of studies concerned with 'misconceptions', 'alternative frameworks', 'children's science', and so on, we begin by considering his account of critical barriers in the light of three closely related questions:

(i) What are critical barriers?

(ii) What are the origins of these barriers? Where do they come from? How do they arise?

(iii) What is distinctive about Hawkins' approach to this subset of learning difficulties.

In the course of their work Hawkins and his colleagues have gradually evolved a "working definition" of critical barriers which helps to throw light on these issues. The definition involves two parts and runs as follows, critical barriers:

1. are conceptual obstacles which confine and inhibit scientific understanding

2. are 'critical', and so differ from other conceptual difficulties in that they:

   a. involve preconceptions, which the learner retrieves from past experiences, that are incompatible with scientific understanding.

> b. they are widespread among adults as well as children among the academically able but scientifically naive as well as those less well educated;
>
> c. they involve not simply difficulty in acquiring scientific facts but in assimilating conceptual frames for ordering and retrieving important facts;
>
> d. they are not narrow in their application but, when once surmounted, provide keys to the comprehension of a range of phenomena. To surmount a critical barrier is not merely to overcome one obstacle but to open up new pathways to scientific understanding;
>
> e. another hallmark of the class is that when a distinct breakthrough does occur, there is often strong affect, a true joy in discovery. (Hawkins, 1980, pp. 3-4).

Over the past decade, his work has centered on the difficulties experienced by adults, many of whom were elementary school teachers, in coming to terms with certain fundamental scientific ideas. He has focused his attention on notions associated with elementary mechanics, heat and temperature, light and colour, size and scale, and the states and properties of matter. In each of these domains, he has set out to explore these barriers and the terrain in which they occur by "collecting specimens and describing them as carefully as possible ... [and] [by] ... formulating hypotheses about them for later study where possible." (1982, p. 2). It is characteristic of Hawkins' work that most of the samples he collected are found in the context of science teaching situations in which he has acted both as teacher and as researcher.

Given that the uninitiated, whether they be children, adolescents or adults, routinely encounter critical barriers in attempting to master elementary scientific concepts, how does Hawkins account for their emergence. From whence do they spring? To be informative the hints contained in the working definition require further explication.

In general terms, he suggests that critical barriers are,"... difficulties due to an apparent mismatch between two conceptual modes: that which is presupposed or communicated in the normal instructional process, and that which is, in biographical fact, accessible for recall and use by a learner" (Hawkins, 1982, p. 1). On this view, the conceptual modes between which this kind of conflict or incompatibility typically develop are those associated with contemporary scientific inquiry, which is presupposed in the normal instructional process, on the one hand, and the commonsense conceptual framework the uninitiated bring with them to instruction, on the other. Before turning to look more carefully at the contrast between commonsense and science, it will be useful to consider Hawkins' account of the process of learning.

He begins by distinguishing between rote, or verbal reception, learning and educationally significant learning. Learning of the first sort is manifested by students who assimilate new information by receiving, retaining and recalling the verbal structures in which it is initially presented. Such learning may be retrievable for demonstrating "competence" on examinations or for solving simple stock problems. However, it remains largely inert in the face of situations that depart significantly from the context in which the learning was originally acquired.

Educationally significant learning by contrast, does engage the learner's current scheme of concepts. As Hawkins (1978) describes it, learning of this kind involves; "...the development of intellectual habits for transforming sensory or verbal information to bring it into congruence or conflict with prior general knowledge or belief" (p. 13). He goes on to suggest that the development of such intellectual habits occurs by means of two somewhat different processes, which seem to closely resemble Piaget's notions of assimilation and accommodation. In characterizing these two processes he invites us to consider the analogy of a "filing system and the contents filed in it" (Hawkins, 1978, p. 16). In some instances, learners encounter new information that can readily be fitted into the categories of their current filing system. Under these circumstances, new information encountered by a student,

> can be filed and retrieved well only if a) there is some sufficient match between its implicit structure or order and the category structure of the receiving mind, and b) there is some consonance between the uses for which the transmitted knowledge-structure was evolved and those to which the student will be moved to employ it. (Hawkins, 1982, p. 16)

In our view, Hawkins' point about the use of knowledge-structures is crucial to understanding critical barriers. Nevertheless, as he develops it, the notion of use, or purpose, is ambiguous. We shall return to this issue later. In other instances, the new information students encounter is such that educationally significant learning will not occur unless there is some fundamental reconstruction or reorganization of their existing filing system.

Critical barrier phenomena, then, inhabit the realm of educationally significant learning. In other words, they are the product of the interaction between different sets of intellectual habits or filing systems: those which serve to animate and organize the knowledge or understanding the uninitiated bring with them to instruction, and those which inform and direct various fields of contemporary scientific inquiry. Hawkins (1982) puts it this way.

> the most persistent and basic difficulties in the acquisition of scientific knowledge are difficulties which involve not so much a sheer lack of information as a trouble in making category shifts, shifts which involve a reconstruction or ways in which experience is codified and filed away, and then later retrieved (p. 18)

Against the background of this account of the process of learning, we are now in a better position to explore and examine Hawkins' view concerning the parts played by commonsense and science the emergence of critical barriers. A closer look at this research will help to reveal the distinctive nature of its contribution to the wider efforts in this field. It may also provide some important clues concerning, among other things, an alternative approach to the education of elementary science teachers.

To begin with, it is vital to underscore the point that central to this research programme is the notion that critical barriers arise due to a discrepancy, or perhaps a conflict, between the frameworks the scientifically naive or uninitiated bring with them to instruction and the elementary scientific conceptions into which we are striving to initiate them. Hence, it is important that we try to get clearer about what Hawkins has in mind when he speaks about commonsense, about science, and the relation between them. Nevertheless, before addressing these issues it will be useful to draw attention to a number of the other distinctive features of this work since they will further illuminate a certain other aspects of the theoretical framework and the methodology that has been employed. First, the principal aim of these studies has been to investigate the relation between common sense and science in certain specific domains, such as those associated with heat and temperature or light and colour, where critical barriers have previously been identified. A second characteristic feature of these investigations is that they have been undertaken in a venue not too far removed from the "teaching ambience". Indeed, they are typically carried out in the context of teaching experiments (in which Hawkins himself has been one of the principal instructors) designed expressly to engage critical barriers. This has been done for a number of reasons including an interest in developing descriptions of, "the precise nature of students attempts to assimilate what is offered in instruction". (Hawkins, 1980, p. 12). Thirdly, and perhaps most importantly, Hawkins (1982) suggests that the models they have developed to represent critical barriers, "are models which impute to our students the same capacities which are implied by our own investigative performance" (p. 17). By this he means that,

> the conceptual apparatus and language we use is of the same genre as the persons we study. Their thinking may be more scientifically naive than ours in some ways, but it does not differ in kind. We impute ways of thinking to them which we ourselves can try to practice and report on, and which can give guidance to our teaching (Hawkins, 1982, p. 17)

Let us now return to our earlier question concerning Hawkins' views regarding the nature of the relationship between science and commonsense in the context of critical barriers. Nowhere in his writing have we been able to discover a systematic and sustained discussion of the relationship between commonsense and scientific knowledge. Nevertheless, throughout there are a variety of hints and suggestions which address different aspects of the issue. Hence, in order to develop a clearer and more comprehensive picture of his views on these matters, we have tried to piece together a number of the things he has said in discussing various aspects of the relationship.

What then would Hawkins have us understand by commonsense? This is an issue of particular interest to us because more than most others working in the field of alternative frameworks, he has ascribed a fundamental role to commonsense in characterizing the views that the scientifically naive bring to instruction. Clarity on this point, then, is indispensable to a better understanding of his conception of critical barriers. To begin with, in one of his earlier studies, he says that the aim was to investigate,

> the relation between commonsense and science in the chosen small area, the relation between what 'everybody' knows and the way 'everybody' thinks about heat and temperature on the one hand, and 'scientific understanding of the topic' on the other. (Hawkins, 1977, p. 28)

Previously in the same paper he describes this relationship as one between

> the rich, everyday, practical lore about thermal experience in the world, where adults and children live --- and the formulations of elementary physics .... (Hawkins, 1977, p. 28)

So it seems that commonsense knowledge or commonsense is to be understood as shared knowledge and ways of thinking about particular topics which play an important practical role in the lives of children and adults. It is important to note the implied distinction between knowledge and ways of knowing, for others have sometimes equated commonsense with one or the other of these. But for Hawkins both are vital to understanding commonsense ways of ordering experience.

Assuming, then, that scientifically naive students come to formal instruction in the sciences equipped not with an empty file drawer but instead with a drawer occupied by files developed under the guidance of commonsense knowledge and habits of thought, which are in some sense relevant to the topic at hand, what is to be made of this filing system? In addressing this issue, Hawkins begins by suggesting that, in certain circles, commonsense has gotten a "bad name". Indeed he notes that on occasion the teachers with whom he worked indicated that they were well aware of the low esteem in which commonsense is held when they agreed that, "the relationship of commonsense to science is *supposed* to be instance of the way error is related to truth, ignorance to knowledge, confusion to clarity" (Hawkins, 1977, pg. 28). One of the teachers put it this way, "the more scientific you are the closer you get to reality" (Hawkins, 1977, p. 28). Indeed, one isn't obliged to go too far afield in the recent misconceptions literature in order to discover vestiges of this same appraisal. From this point of view, in other words, those who happen to think that humans are not animals, that whales are fish, that air has no weight, that the sun rises and sets, or that peas and beans are not fruit, and so on, are seen as being firmly within the clutches of an obvious misconception.

Hawkins and his colleagues take a very different view. It is their contention that, "commonsense is not wrong or 'primitive'" (Hawkins, 1977, p. 28). In contrast, they maintain:

> that 'unscientific commonsense' and science deal with same range or overlapping ranges of phenomena, but with different purposes and perspectives; that each way of thinking seems strange when viewed from the vantage point of the other'. (Hawkins, 1978, p. 28)

This comment is suggestive but requires further clarification. In what particular ways can the perspectives and purposes of science and commonsense be said to differ? In a subsequent paper (Hawkins, 1978) he has taken the position that,

> the commonsense-perceptual categories are inherently a different sectioning of experience than that of modern science more discriminating for many of the purposes of common life but less significant as abstractly universal. (p. 11)

The idea here seems to be that both commonsense and scientific knowledge can be seen as involving systems of categories that carve up experience along different lines and that subserve purposes related on the one hand to the practical affairs of everyday life and on the other to the pursuit of scientific knowledge.

What begins to surface here, and what Hawkins has gone on to treat more explicitly in his report to the NSF (1982), are a series of fundamental issues concerning the nature of knowledge, the way in which it is organized and the role played by human purposes in shaping its organization. Coming to terms with these issues is vital not only to getting clear about his account of the nature of critical barriers, but also to understanding the efforts of he and his colleagues at devising ways of enabling the uninitiated to surmount these barriers. And it is to this same source that some of our questions, doubts and uncertainties--'criticisms' would be too strong a word--concerning the theoretical framework and the programme of experimental teaching and research can be traced.

Accordingly, we want to briefly pursue one or two of the fundamental assumptions on which Hawkins' view of the nature of knowledge appears to rest. In the first place, following Aristotle, he seems to adopt the position that:

> A mind's fund of knowledge is organized *per genus et differentiam*, as a taxonomy, as a filing system in which each genus is subdivided by differentiating characteristics into two (or sometimes more) sub-genera. The defining characteristics of each taxon, each genus are chosen, but only more or less adequately, to be those which are *essential*: that is, to be just those characteristics which are most reliably associated with many others. (Hawkins, 1982, p. 8)

A number of important questions arise here, given our interest in critical barrier phenomena. First, what is involved in identifying an essential characteristic of a genus or taxon. And, second, would certain changes in the taxonomy or filing system, or the purposes it subserves, alter those characteristics judged to be essential or defining? Finally, if there are alternative systems of classification, under what circumstances and on what grounds might we judge one classificatory scheme to be more adequate or suitable than another? Now these are all very large and complex issues. We have raised them here merely in order to try to further clarify Hawkins' conception of a critical barrier.

In reference to the first issue he seems inclined to the view that the defining features of a genus, the characteristics regarded as essential, involves an element of discretion. For example, in this connection he reminds us of what Aristotle long ago pointed out, namely that, "the category *man* is a subdivision under animal distinguished by *rational* [yet] the genus *biped* and the *differentia featherless* would equally distinguish us from the other animals" (1982, p. 8). Thus it seems evident that the matter of what kind of animal man is, what mans' essential characteristics are, involves an element of choice or decision. Which of these characteristics is to be chosen as essential? And by appeal to what criteria is that decision to be made? On Hawkin's view, the notion of rationality is to be preferred because it, "would provide a far more useful (because more coherent) organization of what we know about man's place in nature" (1982, p. 9). In other words, the judgement as to which characteristics of a genus or taxon are defining or essential is based at least in part on the purposes for which the taxonomy is being constructed. And it will also depend on our current knowledge of the subject at hand. Thus in the present example the criterion in the light of which rationality is seen to be essential is one having to do with the pursuit of further knowledge, including perhaps most importantly scientific knowledge.

From this it also seems to follow, in response to our second question, that significant changes in our background knowledge or theories in a particular field of inquiry, or in a cognate field, may serve to alter the prevailing view about what characteristics of a thing are to be thought of as essential. A good example of precisely these sorts of changes can be found in the dramatic restructuring that took place in the system used to classify planetary objects during the Copernican Revolution. Here we witness a significant change in the characteristics used in defining a planet.

Finally, and this brings us back to Hawkins' view concerning the contrast between commonsense knowledge and science, he maintains that human knowledge is not all of apiece, that it might be organized by means of a number of different filing systems serving a number of rather different purposes. In allowing for this possibility, however, he seems concerned to avoid falling into the trap of a kind of Jamesian relativism according to which, "what we regard as the essential characteristics of things is wholly relative to the dominant purposes for which we use or take account of them" (Hawkins, 1982, p. 9). Nevertheless, in the context of his analysis of critical barriers he does want to make room for different systems of classification which treat different characteristics of a thing as essential depending, if not wholly, at least to some extent, on the purposes they subserve.

How then, or in what ways, does scientific knowledge differ in the way it is organized from commonsense knowledge? On Hawkins' view, there seem to be two principal differences: the first has to do with the way in which particular categories are defined within each framework; the second, with the way in which categories are related to one another within each of these systems. "Commonsense categories", Hawkins (1982) contends,

> tend to be defined (implicitly) by relatively accessible characteristics and, where these are not reliable indicators of other consequential traits, we tend to define by clusters of such characteristics, ...; by some kinds of perceived pattern similarly, 'family resemblance.' (p. 10)

Later on, he suggests that by 'relative accessibility' he means readily observable. So, for example, in contrasting scientific and commonsense concepts of a metal, he points out that the twentieth century solid state physics conception is defined by "an atomic crystal lattice structure in which the outer electrons are very easily detachable within the lattice, forming a kind of 'electron gas'" (p. 12). Characteristics such as these are well beyond the reach of everyday macroscopic experience. Commonsense, on the other hand, treats certain more readily observable properties as defining, such as shineiness and heat conductivity. A question we have here, prompted by recent work in the philosophy of science, in particular by the thesis of the theory-dependency of observation, is under what circumstances do such characteristics become readily observable? Are they equally accessible to all observers--regardless of their background knowledge and experience? Or does their accessibility depend on the observer's grasp of relevant elements of the commonsense conceptual scheme?

The second way in which commonsense and scientific category systems differ on this view, is in terms of whether their categories are "tightly" or "loosely connected". "Scientific concepts", in Hawkins' (1982) words, "often form an interconnected network. Any *one* such concept is to be understood as a node in a network involving *other* scientific concepts, tightly interconnected. Commonsense concepts, by contrast, are often loosely connected ..." (p. 15). He goes on to explain that the looseness in the logical interrelations among concepts of this latter kind enables us to "establish them one by one"; whereas, in the case of the conceptual schemes of the sciences," to understand any one concept, ... , it is necessary to understand many others as well." (p. 15). From what he says here it sounds very much as if Hawkins is advancing another thesis, also current in contemporary philosophy science, to the effect that the meaning of a given scientific term depends upon the theoretical framework in which it is used. What puzzles us here is why he is tempted to assume that this is a feature peculiar to scientific terms. Surely it is implausible to suppose that commonsense terms, even such terms as 'shiny' or 'conducts heat', can be "established" or understood "one by one". This sort of suggestion prompts us to speculate about how a child reared in a culture, where the native language was that of contemporary solid state physics, might happen to go about "establishing' the concept of a metal. Even here, in a situation in which common experience would be vastly different from our own, it nevertheless seems reasonable to suggest that terms would have to be learned or established in relation to other terms in the conceptual network, regardless of how loosely or tightly the nodes were connected.

If the latter two considerations are on the right track, they begin to suggest, not that there are no important differences in the way commonsense and scientific knowledge are organized. Rather they are meant to imply that it might be equally important to explore more deeply and in more detail the nature and content of the relevant kinds of everyday experiences, and the underlying purposes which play a role in shaping these experiences. As Hawkins himself acknowledges, only some of the activities in which human beings engage involve the pursuit of knowledge for its own sake. Many of the other activities constitutive of life in society are animated and informed by conceptual schemes which subserve a diverse array of purposes, including those deeply implicated in the practical affairs of life. We need to develop a better understanding of how the conceptual schemes of commonsense are organized and adapted to serve the practical purposes of everyday life. Indeed, there are some tantalizing hints in the research we discuss in part II which suggests that commonsense categories when carefully explored may turn out to be unexpectedly rich and well adapted to serving multiple and in some contexts competing purposes.

Hawkins (1978) begins his essay entitled "Critical Barriers to Science Learning" with the observation that in attempting to understand and help pupils surmount critical barriers,

> We are up against something rather deep in the relation between science and commonsense; we are up against a barrier to teaching in the didactic mode which has hardly been recognized, or if recognized has been seen mainly as a challenge to ingenuity in teaching rather than as a challenge to the deeper understanding of human learning. (p. 7)

What our explorations, both of Hawkins' conceptual framework and the work he and his colleagues did with elementary school teachers, make abundantly clear is that in confronting critical barriers we are up against something very deep in our efforts to understand human learning. What the discussions thus far are meant to underscore is the fact that we regard the notion of a critical barrier as a rich and powerful one especially for exploring the very complex nature of the relationship between science and commonsense in the context of these familiar learning difficulties. In this part of the paper the primary aim has been to examine and attempt to clarify certain central features of Hawkins' conception. One of the chief difficulties we have encountered is in attempting to get clearer about what he means by science and what he means by commonsense. More particularly, we have tried to clarify his views concerning the interplay of content and purpose in shaping the conceptual schemes of science and commonsense understood as forms of knowledge or filing systems for organizing experience. Although generally sympathetic to this analysis; we have a number of reservations which revolve around two tendencies which show up here and there throughout his work. The first is a tendency to overlook some of the ways in which commonsense knowledge is more similar to its scientific counterpart in respect to its organization than he suggests. And the second is to underestimate the distinctiveness of the purposes which serve to organize the content of the two frameworks and guide the activities and experience they inform. Both of these tendencies grow out of his efforts to walk a tightrope between Jamesian relativism on the one side and Aristotelian essentialism on the other. For example, in contrasting common sense and scientific systems of classification, he notes that in Mobey Dick a whale is classified as a fish with a horizontal tale; whereas in contemporary biology it is categorized as a cetacean mammal. Following James, he allows that these two systems reflect, "characteristic human interests and purposes". At the same time however, following Aristotle, he also wants to insist that the second of the two descriptions is to be preferred because it, " 'divides nature at the joints', which the first, to a degree, does not" (Hawkins, 1982, P.11). So, while Hawkins is prepared to acknowledge the existence of alternative systems of classification involving differing conceptions of a whale, tailored to fit differing interests and purposes, he nevertheless ventures very close to maintaining that scientific purposes take some sort of precedence, even, it seems, in the domain of common sense. He puts it this way,

> Thus we can admit that classification is relative to the purposes for which it is organized, but we can observe, all the same, that some classifications can serve a far wider variety of purposes than others including, most importantly, the further pursuit of knowledge (Hawkins, 1982, p.11)

Given that the principal goals of the scientific endeavour include the further pursuit of knowledge, the desire to develop richer and more coherent ways or organizing our scientific knowledge of "man's place in nature", and so on, there can be little doubt that the currently accepted biological conception is to be preferred. And should an alternative conception of a whale emerge within the scientific community at some time in the future, it seems perfectly reasonable to suppose that the merits of the newer conception will be judged by comparing it with the then current view in the light of the unfolding purposes of scientific inquiry. In other words, so long as it is clear that aims such as the pursuit of scientific knowledge are to be relied on to judge the adequacy of scientific conceptions then this account seems to be a plausible one. What troubles us, however, is the further suggestion that it may be equally appropriate to call on these same purposes in assessing the relative merits of scientific as compared with commonsense conceptions. Were we to take up this suggestion, we may be prompted to succumb to the temptation to regard the notion that a whale is a fish, or that a tomatoe is a vegetable (as distinct from a fruit), as in error, wrong or, in a word, as a misconception.

Yet, under these circumstances, we seem obliged to confront Wittgenstein's question "If we call this 'wrong' aren't we using our language game as a base from which to combat theirs?" By adopting this view, we may be led to impugn the integrity of commonsense conceptions, or the language games in which they play vital roles, on the ground that the "rich, everyday, practical lore" of commonsense amounts to little more than ... some rather loose amalgam of "folk biology", "folk physics" etc., and can therefore be judged on its adequacy for pursuing scientific ends. What this view ignores is the possibility that common sense concepts or categories provide a different sectioning of experience precisely because the pursuit of scientific knowledge is not the only or even the most important goal they subserve.

In short, then, while we see it as one of the great virtues of Hawkins' work on critical barriers that it helps to restore the integrity of commonsense concepts or theories, we are worried that at times it seems to overestimate the importance of the pursuit of knowledge for its own sake in the practical affairs of living.

How in the light of these reservations might critical barriers be seen. Phillip Morrison (1985) suggests that critical barriers are the product of a collision between commonsense and scientific ideas, and that such collisions are typically the chief basis of their identification. These collisions, he maintains,

> do not represent so much the inadequacy of logical categories and operations-- ... --but rather the systematic, if less than conscious, application of workable and even tested commonsense theories within domains where their utility fails. (p. 45)

In order to better understand critical barriers, then, still more serious and sustained attention must be paid to commonsense theories in the domains in which their utility does not fail.

We now turn to a preliminary exploration of the approach to teaching and learning used in Hawkins' empirical research on critical barriers.

II. The Empirical Research: Helping Teachers Confront Critical Barriers

Two types of courses were offered, one for undergraduates and one for experienced elementary school teachers. We will focus on the two courses for elementary teachers held during the spring and fall semesters, 1981 at the Mountain View Centre, Boulder Colorado. The topics for the first course were Size and Scale and Heat and Temperature. The second semester dealt solely with Light and Colour. The teachers in these courses (about 10 in each) were selected on the basis of their responses to descriptions which were circulated by the research group. The teachers participated with some understanding of the dual purposes of the project which were:

> i) to help them learn more elementary science, relevant to their own teaching
>
> ii) to enlist their help in describing and accounting for the conceptual difficulties they had already experienced in learning science, or would experience under the tutelage of David Hawkins and Ron Colton (the instructors). (Hawkins, Apelman et al, 1982, p.iv)

Hawkins states in the preface of his report that "the major source of evidence concerning critical barriers and related matters is derived from these two courses." (Hawkins, Apelman et al., 1982, p. iii). We believe this work has special significance for classroom teachers because it has helped to,

> define a major area of educational search and research, and by positive findings in this area have demonstrated the feasibility of a style of investigation very close to the normal work of the classroom. (Hawkins, Apelman et al., 1982, p. v)

A noteworthy aspect of this project was the dual role played by Maja Apelman, one of the investigators. She also participated as a student with the other elementary teachers and acted as a liaison between the remaining investigators and the teachers. David Hawkins described her role in the project as follows:

> Dr. Apelman, a long time member of the staff of the Mountain View Centre, experienced as a teacher of young children and as a professional advisor to elementary school teachers, describes herself as a scientifically naive, encountering conceptual difficulties in science which are often on par with and tuned to those of the students she is observing. (Hawkins, Apelman et al., 1982, p.ii-iii)

From reading her reflections, it is obvious that she was able to raise issues and describe crucial encounters between instructors and the teacher participants which otherwise would have been missed. We will draw extensively from her work in an attempt to give you a feeling for what went on during these sessions. Included in her section of the research report are frequent comments made by the teachers and instructors during the actual classes.

These comments are a rich source of information about the teaching-learning process. They provide valuable clues concerning how we might help elementary teachers come to understand the nature and importance of critical barriers. And, at a different level, the ideas described here suggest the importance of the teacher as classroom researcher.

David Hawkins began the first session of the course on Size and Scale with the observation that from his experience many people have difficulty in understanding surface area. He was intrigued that something which to him doesn't appear to be very difficult could cause so much trouble for so many people. It is important to note that Hawkins doesn't believe the difficulty exists as a result of a lack of intelligence. Rather, a goal of the research was to find out why commonsense was so at odds, at times, with scientific understanding. He told the students:

> ... if people don't understand something, it is not because they are stupid, it's because they have preconceptions which they have learned, and often learned under conditions which make these preconceptions useable and useful. Then we require that people give them up. It's like giving up a friend. (Hawkins, Apelman et al., 1982, Section D, p. 2)

He went on to explain that his interest was in the students' difficulties in trying to understand this difficult way of conceptualizing, in finding out how a person was thinking, in the so called 'naive' questions people might ask. Hedy (one of the students) exclaimed, "Imagine being valued for that!" (Hawkins, Apelman et al., 1982, section D, p. 3). A good deal of time could be spent considering the implications of that comment.

Having laid out those rather unusual ground rules, Hawkins began the exploration of size and scale by demonstrating the effect of beating soapy water with an egg beater. David drew the group's attention to the change in the mix (it was growing in volume and getting stiffer) and by way of explanation said:

> There is an awful lot more internal surface of little bubbles, there are more and more little bubbles and if you could measure the total amount of surface where there is liquid and air in contact with each other, it increases and increases and increases. There is a big change in the ratio of volume, of water to the surface area that the water has in common with air...and the bigger you make the surface, per unit volume, the stiffer the stuff gets. (Hawkins, Apelman et al., 1982, section D, p. 3)

Most of the group was totally confused with these ideas. Questions were asked, answers were attempted but the confusion seemed to grow as quickly as the soap bubbles. Maja asked for a parallel example that might help her understand what was happening to the soapy water. Ron Colton, the other instructor drew attention to differences between large and small water drops and introduced the word 'stability'. This caused even more confusion among the students, they were not making any of the connections that the instructors hoped they would with the chosen activities. We have an interesting problem developing here, one which would repeat itself many times. The students couldn't figure out what they were supposed to be seeing and understanding and the instructors couldn't figure out why the students couldn't make 'science' sense out of the activities. We also must remember that Hawkins invited the students to share their questions and concerns with the group. He knows that the students and instructors were 'seeing' different things and this was exactly what he was trying to make sense out of through this research. His challenge, now that he was becoming more aware of the students' problems, was to create situations which would begin to link the students' commonsense views with the scientific way of making sense.

Sally, another of the students, wrote the following after the first class:

> ... How do they know that the mixture becomes more solid because the surface area of the bubbles becomes greater, thus creating more strength? And how do they know that increased surface area in relationship to the volume creates strength? ... I'm taking someone's word for it as I always have in science. Could you actually see the surface of these bubbles through a microscope and analyze the relationship between surface area and volume? Where is the starting point for this understanding? (Hawkins, Apelman et al., 1982, section D p. 5-6)

The second class began with the students observing the behaviour of water drops on wax paper. There was little direction from the instructors except for the students to try different things which seemed interesting (messing about). Interest in this activity was high and many observations were made by the students:

Ann: It's fun to watch the little drops be gulped up by the larger bubbles. (Hawkins, Apelman et al., 1982, p. 7)

Hedy: I'm amazed at how self-contained each bit of water is ... they have charm. (Hawkins, Apelman et al., 1982, p. 7)

Maja: How come the water isn't wetting the surface it is on? [wax paper] (Hawkins, Apelman et al., 1982, p. 7)

David then put a bit of soapy water on some of the drops and they immediately disintegrated. This created more confusion:

Hedy: How could soap destroy a water drop but strengthen a water bubble? (Hawkins, Apelman et al., 1982, p. 8)

Other confusions began to surface as well for students who went back to beating soap bubbles:

Mary: I have difficulty imagining what must be actually happening since air is invisible. (Hawkins, Apelman et al., 1982, p. 8)

Still others remained with water drops and became fascinated with their magnifying ability and inverted reflected images:

Sally: ... It's exciting to think I might have observed something and learned from the observation. But after all that looking and questioning, why is it that I wonder if I've drawn any correct conclusions? ... in science I don't have the back-ground to know if what I think makes sense. (Hawkins, Apelman et al., 1982, p. 9)

Sandy: ... how quickly I abandoned that track of thought when it did not meet with shared interest, or when I sensed that it might be the least bit obvious. (Hawkins, Apelman et al., 1982, p. 9)

Hedy: [she had asked David a question] That was not what he wanted me to be thinking about ... I just had some of that older feeling of I'm not doing it right, whatever it is ... I've got to go where he's going and I don't know where that is. (Hawkins, Apelman et al., 1982, section D, p. 10)

Apelman writes about these reactions:

> One couldn't imagine a more relaxed, more supportive setting than the one we tried to create for these meetings but old feelings are strong and it didn't take much to bring them out. (Hawkins , Apelman et al., 1982 section D, p. 10)

Shelly had a different response to the activities:

> All of these things kept me so absorbed that I didn't want to join the others doing something else. I couldn't handle any more ideas! ... I left feeling stimulated but a bit drained and frustrated too ... I feel I'm at a stand still and there is so much to learn. (Hawkins, Apelman et al., 1982 section D, p. 10)

Apelman makes an important connection between this feeling of 'there is so much to learn' and Hawkins' approach to teaching science:

> ... David ... believes in starting with broad complexities rather than with premeasured little units which can be memorized but which rarely take you to the larger more exciting understanding of science. (Hawkins, Apelman et al., 1982, section D, p. 11)

The next class began with a discussion mainly dealing with this kind of student concern: "Why are we doing all of this? Where is it taking us? We don't see what it has to do with size and scale" (Hawkins, Apelman et al., 1982, section D, p. 11). Hawkins realized that what he had hoped would result from these activities - important elementary insights into size and scale - hadn't happened. The class had not made the leaps in understanding. Also, the open-endedness of the activities (planned by the instructors) had allowed students to go off in many directions, but this led to many 'awkward, off topic' questions. Marsha asked: "Why would cream whip and not oil?" (Hawkins, Apelman et al., 1982, section D, p. 12). David replied:

> There are lots of phenomena that you can observe and get interested in ... what do you do with kids when they ask why questions, like the child asking where living things really came from? You say to yourself: "Oh Lord, the words that I would use would not be understood," and you try to direct their attention back to more things they can learn at their level. You probably evade their questions. I can tell you right now I haven't the vaguest idea what sort of answer to give to that. I think I could begin to evade it somewhat. Could you whip butter into foamy stuff? Butter is the fat, cream is a mixture of other things.

> I can see a difference between cream and oil. (Hawkins et al, 1982, Section D, p. 13)

David's dilemma about what type of answer to give is central to his approach to teaching-learning. He knows an answer but he also knows it won't make any sense to the questioner because through working with the learner, he's beginning to appreciate the implicit preconceptions of the questioner. He could come up with a suggested activity which might lead the questioner towards an answer or he might ask the questioner to postpone that concern and trust him to reintroduce it when the time is right. Hawkins' frequently used both of these strategies during the classes, he also occasionally tried to answer the question--rarely with any success.

Consider some of the questions coming at him:

> Ann: Why are the images upside down [in the water drop]?
>
> Hedy: Why does soap make water drops collapse?
>
> Mary: [talking about the bubbles in the soap froth]
> Isn't it that way because of the hydrogen bonding? (Hawkins, Apelman et al., 1982, section D, p. 13)

In the light of the existing confusion in the minds of the learners, David was reluctant at this point to introduce talk of atoms and molecules. Instead he redirected Mary back to some more basic observations.

Maja was having serious difficulties figuring out how and why the word 'stable' was being used to describe soap bubbles. She asked David it if meant strong:

> David: You notice that this bubble lasted longer?
>
> Maja: Yes. That's because it is stronger. Now I can't say that anymore.
>
> David: Yes, but you have a because in there which I wouldn't have. I was just saying it lasts longer. I'm just describing a thing that means it's more stable.
>
> Maja: I see, lasting longer means greater stability to you. It means that?
>
> David: It's just the same thing. It's not an explanation of it.
>
> Sally: He's defining stability.
>
> David: It's not an explanation of anything, it's just a description ...
> Maja: It always means lasting longer?
>
> David: Yes, it's always protection against shocks or disturbances ... There is no sense of contradiction there (when you use stable) whereas when you use the word stronger you seem to be initiating a contradiction. (Hawkins, Apelman et al., 1982, section D, p. 15)

This exchange powerfully illustrates how difficult it is for people operating from different frameworks to share their understandings and meanings with each other. Later questioning by Maja prompted David to introduce molecular theory. Maja was willing to accept David's explanation, without really understanding it. Knowing when one should be only describing and when one should be trying to explain is not as obvious to the learner of new ideas as it is for the instructor to whom these distinctions are "second nature". Once something makes sense to you, it's hard to figure out why someone else can't make the same (similar?) sense. It is like trying to get someone to see an optical illusion but no matter how hard you try to explain it, he or she just can't see. However, if 'seeing' (understanding) is what you as a teacher strive for with your students, it remains our biggest challenge.

Maja asks the reader a similar question:

> How do you know when students are ready to think in terms of atoms and molecules? Timing is always one of the most difficult questions which teachers have to face. David, I think, prefers to err in the direction of being too late. Most science teaching errs grossly in the opposite direction. (Hawkins, Apelman et al., 1982, section D, p. 17)

Apelman develops this idea further later in her text. She is concerned about language and understanding:

> Because it is easy to talk about molecules and atoms, to use the labels without understanding the concepts, David wants students of all ages to have a broad knowledge built on observation and experimentation before talking about the physical world in terms of atoms and molecules. (Hawkins, Apelman et al., 1982, section D, p. 19)

Hawkins' deep understanding and appreciation of the historical development of scientific ideas is greatly responsible for this approach to teaching-learning. He says:

> I would have liked to have kept us in the 18th and 19th centuries for a while so we could arrive at an understanding of heat which paralleled the historical scientific development of the subject." (Hawkins, Apelman et al., 1982, section D, p. 16)

Since soap bubbles and water drops hadn't accomplished as much as anticipated, Hawkins and Colton, with input from Apelman, decided to try wooden cubes. Then, due to new confusions and questions, they tried exploring the area and volumes of fruits and vegetables and with similar results moved on to shape, size and volume with plasticine. Each new experience provided a few new insights, but it mostly seemed to create more confusion and questions. At the heart of this confusion was the failure of the instructors to appreciate all the interrelated understandings they had which were in no way part of the students' thinking. What seemed like effective activities and demonstrations to aid students in seeing the point, missed the mark.

A decision was then made, based on the group's interest in exploring size and scale in the biological realm, to play with the idea of altering the size of an elephant. The investigators assumed that by now the students had enough understanding of what happened mathematically when you scale an object up or down to deal with this new activity. The instructor started by having the students imagine what would happen if an elephant's linear dimensions were doubled. He was in no way prepared for what followed:

Instructor: Let's take an elephant. He weighs 5 tons, 10,000 pounds. His main body part is about 10 feet long. So let's make the elephant twice as long and that means twice as long, twice as thick and twice as high. I'm going to double his linear dimensions.

Maja: From where are you measuring him?

Instructor: I'm going to take his square body. (The instructor had drawn a sort of cubist elephant on the blackboard.) What happens now if I make my elephant 20 feet long, 20 feet wide and 20 feet high? I've doubled all the linear dimensions. I've made a gigantic model and everything is twice as long. How much bigger will the volume be?

Mary: I don't know how to figure out the volume. I know we've figured that out but at this moment, I don't know.

Sally: Those things really leave you fast, don't they?

Instructor: (Uses the wooden cubes to demonstrate the volume growth.) Twice as long, twice as wide, and twice as high. Eight times the volume.

Mary: (Building her own model) 2 x 2 x 2.

Instructor: Here is my first elephant. If I make him twice as long and keep him the same shape, I have to make him twice as wide and twice as high. So he's eight times as big in terms of volume and therefore weight. There are eight of these elephants (pointing to the cubes) in that.

Mary: Are these arbitrary numbers, the 10,000 pounds?

Instructor: That's about right for an elephant.

Mary: But what does that have to do with the 10-foot dimension?

Instructor: An elephant is about 10 feet long and weighs about 5 tons.

Mary: OK, but you could have used any number, and then would the second number relate to it?

(Mary is asking an important question, but at this moment the instructor could not take the time to deal with it.)

Instructor: That much elephant is 10 feet long and it weighs 5 tons. I don't think that we ought to get too tied up with number relationships. OK, if I make him twice as long, to keep him still looking like an elephant, I'm going to have to make him twice as wide and twice as high. I'm going to have eight times as much elephant so I'm going to have 40 tons of elephant.

Jean: If you make him twice as big, do you double him too?

Instructor: Look, I did this, I doubled all the dimensions so I've got eight times as much elephant. Does everyone see this?

Mary: Yes, I do understand that. I guess what I don't understand is the connection, well, so you say he's ten feet across, ten feet high and ten feet wide. So you multiply the ten times eight to get some number which is eighty.

Instructor: All I'm saying is: my original cube weighs 5 tons and I'm going to have eight times as much. There are eight of those cubes in my new elephant so he's going to weigh eight times as much.

Jean: If you wanted twice as much elephant, you wouldn't just go get another 5 ton elephant?

Instructor: I wouldn't know what to do.

Sally: Well, now if you said you wanted twice as much elephant, maybe you need an elephant that weighs twice as much.

Instructor: Yes, I think you might.

Jean: That's what I'm trying to find out, that's what I said about doubling and twice as much being the same thing.

Instructor: But this is a new kind of creature we are inventing now.

Mary: Even if you doubled the linear dimension, you could double the weight and have twice as much elephant.

Maja: Or even the area if you chose to double the area.

Instructor: Yes, but I'm being very precise and I didn't say I was going to have twice as much elephant, I said I was going to double each linear dimension. There are three: twice as long, twice as wide, twice as high. 2 x 2 x 2 = 8.

Jean: I'm having trouble with what you call that 8, is that the volume? And what is the 5 ton?

Instructor: That's the weight of the original elephant.

Jean: What's the difference between weight and volume?

Instructor: It just happens that this much elephant weighs 5 tons. That much wood would weigh 3 tons, or that much lead would weigh 100 tons. But a piece of elephant 10 x 10 x 10 just happens to weigh 5 tons.

Ann: I'm getting confused about twice and doubling.

Myhra: Doubling and twice as much? They are not the same, right?

Instructor: In linear dimensions, if I make something twice as long, I'm doubling the length, aren't I? And I was very careful to say: we will double the linear dimension.

Ann: OK, so are you saying they are the same?

Instructor: Twice as long, double the linear dimension.

Sally: I want to go back to what Jean was talking about, because I don't think the 5 tons was a relevant thing. The elephant could have weighed 4 tons, he could have weighed 5 tons, or he could have been a baby elephant and weighed 1 ton. But whatever he weighed, if you double his length, he is going to weigh eight times as much. So if he was a baby elephant and weighed 2 tons and you doubled his length, width and height, he is going to weigh 8 x 2 which is 16. He is going to weigh 8 times as much because he's got eight of those (cubes).

Jean: It's even more basic than that, I don't understand what the definition of volume is, I guess.

Mary: I think that is what I was getting mixed up with too, wondering if that 10,000 pounds is somehow a result of his dimensions. (Hawkins, Apelman et al., 1982, section D, p. 34-36)

The instructor had hoped to quickly get the students to think about and appreciate why animals can't keep their same shape and be much bigger or smaller than they are. It obviously didn't work. Once you have encouraged students to voice concerns, confusions and questions when they aren't following what is going on, the challenge of teaching greatly increases. Does the instructor show any sign of frustration in his responses to the students' questions and comments? If so, is his frustration based on his not being able to understand the students' misunderstandings? Is this frustration (confusion) on his part any different than the frustration and confusion learners experience when they can't figure out what a teacher means? Where does the major onus for sorting out this confusion lie--with the teacher or with the learners?

At the staff meeting following this session, efforts were made by the instructors to make sense out of the students' confusion. It seemed to be an inability to make an important connection between two notions of volume (notions which are closely connected for those who see the connection).

> David: [explaining to the staff]
> ... there are two ideas about volume that have to be connected, one is a container that has a certain capacity and the other is what fills the container. (Hawkins, Apelman et al., 1982, section D, p. 38)

It is not clear from the research report whether the importance of this distinction has been appreciated by the investigators prior to the elephant activity, or only after the activity had been tried. Our guess is that it was appreciated only after the students expressed their concerns. This kind of learning on the part of the instructors exemplifies the importance of the role of teacher as researcher. Appreciating students' understanding and encouraging students to voice concerns etc., allows the teacher to reflect on the effectiveness of his attempts to bridge the students commonsense understanding of phenomena with the understandings held by science. To what degree can we eliminate confusion as we attempt to help learners build those bridges?

Each time the research staff came together after a session it became clearer that 'simple' ideas and activities are not so simple. In fact they are made up of intricate interconnecting webs of experience, concepts and understandings. The attempt to eliminate one area of confusion with a certain activity usually introduced new areas of bewilderment along with some new insights. It also became clear that certain activities created 'wrong notions' which actually interfered with the students overall understanding of the major concepts being learned (i.e., size and scale). The work on volume using uniform sized wooden cubes had encouraged the students to think of increases in volume by fixed amounts. David now saw this as a hindrance:

> David: ... we really need to get away from fixed units that you count. Think instead of length and areas and volumes as volumes that can change by arbitrary amounts.
> (Hawkins, Apelman et al., 1982, p. 40)

As the group began to work with irregular shapes, however, it became obvious that their intuitions about volume were quite poor. Students gave personal, real life, examples of their 'poor' ability to estimate certain volumes (e.g., loads of topsoil, gravel). It was decided that the students needed lots of experiences dealing with volume of various shapes and sizes. Maja ended the session by asking David to give them an idea of where a new understanding of these concepts would take them if they gained more fluency with them. Hawkins responded:

> For Ron, it would be the fact that you cannot scale living things while keeping their form exactly the same. The only way you can succeed in getting bigger living things is to change their form. It's the nonscaling involved in living things that's a fascinating and very rich topic. For me, in a much wider sphere of application, it has to do with the way the properties of things change with size in general, not just for living things. Why little drops of water would sit on a wax paper and make all those perfect spheres while big globs of water will flatten out and make almost flat surfaces. Why things that are bigger than the planet Jupiter are fiery hot and why things smaller than the planet Jupiter are apt to be fairly cold. Why things bigger than the moon are always round. If these things were well learned and acceptable in the imagination, they would give you a kind of classification system for all the furniture that has been discovered to exist in the natural world from atoms to galaxies. (Hawkins, Apelman et al., 1982, section D, p. 42).

In the final two classes teachers used all the materials they had collected for work with volume in an attempt to clarify some of their questions. Shelly's work led her to write:

> I was finally doing what I really wanted to do back in highschool geometry. I had so much trouble with solid geometry and the sad part is that I don't think I ever even handled, much less investigated, a cone, sphere, etc. They were always drawings. So it was very exciting to discover the volume of a cone on my own. (Hawkins, Apelman et al., 1982 section D, p. 43)

Eight weeks (16 hours) had been spent on investigating size and scale. Many more questions than answers had been created, but many in the group had begun to believe in their own ability to understand these ideas over time, through observation with guidance and support. Hedy expresses well most of the group's feelings:

> I don't feel frustrated by this. Motivated, curious instead. Saying that suddenly makes me cry because for me to even have and express such a thought is so brand new ... I have simply never felt friendly towards those subjects.
> (Hawkins, Apelman et al., 1982, section D, p. 46)

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SELECTION OR ADJUSTMENT? EXPLANATIONS OF UNIVERSITY BIOLOGY STUDENTS FOR NATURAL SELECTION PROBLEMS

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1. INTRODUCTION

The first issue approached by research on Education, and particularly on Science Education,is the learning problems pupils experience. Why,very often,do they not learn? Why do teaching strategies prove ineffective?.

So far,we have only partial answers to these crucial questions. Science Education - or shortly,Education - lacks a widely accepted,fully tested teaching-learning paradigm. Nevertheless,in the last few years,a useful model has emerged which is guiding research,based on cognitive psychology and constructivist epistemology (Driver 1986,Novak 1986). Though we cannot view it as a magical recipe to solve every problem that comes up in the classroom,it offers a framework to Science educators,teachers and researchers.

As research has focused on models which pupils (and adults) build in order to interpret natural phenomena,a number of studies (Driver et al 1985,Gil & Carrascosa 1985,Giordan 1987,Osborne et al 1983) have been carried out lately on the features of these informal models and the difficulties to change them to the accepted scientific ones through teaching practice. These informal theories,or conceptual frameworks investigated,seem to share a number of features,some of which,in Driver's opinion,(1986) are:

* They differ from accepted scientific theories.
* They persist,despite formal instruction
* The same informal theories are used by different individuals and over a wide age-range.

This study is part of a more comprehensive one dealing with the structure of the conceptual frameworks concerning the understanding of Evolution through Natural Selection by Secondary School and University students in Spain. Following a study on the explanations given by first and last year Secondary School students (14 and 17 year-olds)(Jiménez & Fernández 1987a),we intend to investigate the conceptual frameworks of University Biology Students,particularly on the following issues:

- Persistence of alternative frameworks among this selected (by professional choice) group of individuals.
- Consistency in the use of the same frameworks in different tasks by individual students.
- Gender-related differences (if any) in the use of accepted and alternative framework.
- Differences in the framework use between University and High-School students.

In this paper we address the first three issues; the fourth being discussed elsewhere (Jiménez & Fernández 1987b).

Student's ideas about Evolution through Natural Selection have been reported by Brumby (1979a & b,1981,1984),Calafate (1986),Deadman (1976),Engel & Driver (1986) and Subbarini (1983). Some commonalities have emerged: the belief of a large percentage of students in the inheritance of acquired characteristics,and the interpretation of adaptation,not as a result of population changes over generations,but as slow processes of changes in individuals.

In her doctoral research,Brumby(1979a) pointed out the inconsistences between the responses of the same individuals. Research on this last issue has recently been reported by Engel & Driver(1986): They found a certain degree of consistency in some of the responses. They suggest that both the context and wording of the questions may account for some of this variation,and that questions that look similar to scientist may not appear so to the students.

2. METHODOLOGY

The sample consists of two groups - taken out of six - of 76 and 81 students,reading for their Biology Degree (second year) in Madrid (University Complutense). As students are assigned to each group by alphabetical order,we believe they are representative of the total. Evolution by Natural Selection is one of the topics studied in the Biology course in the Senior year of High School(called COU),and is also included in the Syllabus of basic Biology courses at University.

The students were provided with a set of three sheets of paper,each containing an application problem related to the subject studied. The words "evolution","natural selection" or "adaptation" did not appear in the wording of any of these problems,as we wanted to avoid rote-memory repetition of textbook definition. The sheets were stappled in different order to have different problems presented in the firs place to students. The test was an Open-Response one,providing no answers.

The three problems appear in appendix 1. We will discuss their features briefly.

- The "Lice" and "Bacteria" problems are quite similar in construction,and we expected students to answer them in the same way. The "Lice" problem quotes a text from a widely known Spanish newspaper,asking students to give an explanation; and the "Bacteria" problem is drawn from the University Access Tests.
- The "Mice" problem,based on Weissmann experiences,was constructed for use in the classroom as a part of some activities intended to promote conceptual change. Our hypothesis was: As the organism implied was a vertebrate,and the acquired characteristic - cutting off the tail - one close to the students' experience,and known not to be passed on,the answers should be,in a higher percentage,the accepted one.

The tasks were fulfilled in one day,instead of a normal lecture,without previous warning,and students were asked to complete them,in order to help in a research project on Biology learning problems.

3. DATA ANALYSIS

Answers to each of the tasks were grouped into mutually exclusive categories,according to the explanations given. Three main categories were established:

A. Explanations according to accepted scientific principles,or incorporating parts of it.

B. Explanations based on post hoc adaptation of individuals and inheritance of acquired characteristics.

C. Others,including teleological,animistic,uncodeable and some lacking answers to one task ("Bacteria").

Subcategories were established,as shown in table 1.

The reason to include rather heterogeneous responses under C category,was our intention to compare accepted explanations against the most extended alternative ones (B). According to this same reason a hierarchy was established,so that an individual's responses including B and C explanations were categorized as B. Sometimes more than one subcategory was involved.

As seen in table 1 we did include explanations based on "becoming immune to " in B 3 (B category) as we consider them related to the idea of reaction to environment changes and inheritance of these acquired features. This does not coincide with other studies on the same ideas.

Categories were established after data study; and we call

Table 1. Categories and subcategories of responses

A. Explanations according to accepted scientific one
  A 1. Including variation and differential survival.
  A 2. Incorporating only part of accepted explanation.

B. Based in reaction to environment and/or inheritance of acquired features.
  B 1. Environment causing genetic changes targeted to a special factor.
  B 2. Individuals "getting used to","adjusting to"...
  B 3. Organisms "becoming immune" and passing this on to offspring.

C. Others
  C 1. Teleological explanations: "in order to survive".
  C 2. Anthropomorphic explanations.
  C 3. Uncodeable,no identifiable framework.
  C 4. Does not answer.

them frameworks according to Engel & Driver when appearing in more than one question context.

We want to note that,being the context of the "Mice" question quite different from the other two,subcategory B 3 did not apply to it.

The process of categorizing student responses was repeated independently by a second researcher. A level of agreement of 90 % in the main categories was obtained.

Translation of some responses and the category assigned to them can be seen in appendix 2.

Table 2 shows the number,percentage and σ (standard deviation) of responses allocated to main categories for each task,and table 3 the number of responses allocated to subcategories.Results are discussed in the next section.

Then we compared frameworks used by individuals in answering to the three tasks,and the differences in percentages of accepted and alternative ideas between boys and girls.

Table 2. Number and % of Student Responses (Main categories)
N = 157

Task/Category	Number Students	% Students	σ
BACTERIA			
A	78	49.68	3.99
B	58	36.94	
C	21	13.37	
LICE			
A	50	31.18	3.69
B	105	66.87	
C	2	1.27	
MICE			
A	93	59.23	3.92
B	56	35.66	
C	8	5.09	

4. PERSISTENCE OF ALTERNATIVE FRAMEWORKS IN DIFFERENT CONTEXTS

As table 2 shows,the proportion of students using accepted framework go from 59.23 % in the "Mice" question to 31.18 in the "Lice" one. In fact, we did expect students to use the accepted framework to a higher degree in the "Mice" task,since the organism is a vertebrate and the situation

Table 3. Number of Student Responses allocated to subcategories (in brackets, those coded under other category).

Subcategory	Bacteria	Lice	Mice
A 1. Differential survival	53	34	58
A 2. Part of accepted explanation	25	16	35
B 1. Environment→ genetic change	22(1)	33(1)	21
B 2. "getting used to"	27(4)	41(2)	35
B 3. "becoming immune"	9(1)	31(9)	-
C 1. Teleological	7(10)	1(11)	6(9)
C 2. Anthropomorphic	1(2)	-(5)	2(1)
C 3. Uncodeable	9	1	-
C 4. Does not answer	4	-	-

can be related to that of a human being losing a limb. Some students - for example 57*, as can be seen in appendix 2 - mentioned the loss of the tail as a "morphological" change that "does not affect genes". This opposition of morphology versus physiology related to genetic changes requires further study.

What we did not expect was the contrast between the responses to "Bacteria" and "Lice". This last task proved the most difficult one, and the number of students using B frameworks - related to inheritance of acquired characteristics - was extremely high. The results support the idea, pointed out by Engel & Driver (1986), that tasks similar to scientists' eyes - or, let us say, teachers - may not appear so to students.

Perhaps the difference in the use of frameworks when carrying out the "Bacteria" and "Lice" tasks, relates to the "scientific" context (a culture in a lab) met in the "Bacteria" task, as opposed to the "everyday problems" context of the "Lice" task. If this is so, and we need further work to confirm it, that would emphasize the need of using in the classroom examples and problems close to everyday life.

The higher use of the accepted framework in answers to the "Mice" problem, compared with the two last, is stressed if we take into account that, having the "Mice" question two parts, responses were coded A only when using this framework in answering to both parts.

In any case, we feel that the fact that only 59.23 % of students - in the "easiest" task - and 31.18 % - in the "Lice" case - are using the accepted idea, is a matter for great concern. Moreover, there is a significant number of students giving teleological explanations, and even some giving anthropomorphic ones. It should be noted that, as responses were allocated to mutually exclusive categories, the ones including for instance both B and C 1 were coded only as B. The answers coded as C 1 offers the "need to survive" as explanation. In table 3, besides C 1 and C 2, figures in brackets the number of teleological and anthropomorfic answers given in combination with other categories, and the same notation is used for B subcategories. These figures in brackets were not considered to calculate the percentages.

Considering this as a selected group of people intending to take a Biology degree, and acknowledging the importance that the Natural Selection topic has in modern Biology, the need for some teaching strategy that takes these problems into account, is clear for us.

5. CONSISTENCY IN THE USE OF FRAMEWORK IN INDIVIDUAL RESPONSES

In order to explore the consistency in frameworks use by individuals, contingency tables were drawn for each pair of tasks. In table 4 a contingency table for the "Lice" and

Table 4. Contingency table (3 x 3) for "Bacteria" and "Lice" In brackets independent values. C coefficient= 0.54

BACTERIA LICE	A. accepted explan.	B. "post hoc" adaptation	C. other	Total Lice
A.accepted	48 (24.84)	1 (18.47)	1 (6.68)	50
B.post hoc adapt.	30 (52.16)	56 (38.78)	19(14.04)	105
C.other	0 (0.99)	1 (0.73)	1 (0.26)	2
Total Bact.	78	58	21	N= 157

"Bacteria" tasks is given as example. For space reasons the contingency coefficient only is given for other pairs of tasks (table 5).

Table 5. Contingency coefficient for each pair of tasks. N = 157

TASKS	contingency coefficient C
Bacteria & Lice	0.54
Bacteria & Mice	0.43
Lice & Mice	0.32

As it is shown on tables 4 and 5 there is a positive correlation between the answers using accepted and alternative frameworks in each pair of tasks,the highest been found,as expected,in the "Bacteria" and "Lice" pair. In fact,all but two of the students who used the accepted framework for "Lice", did the same for "Bacteria".

Table 6. Contingency table (3 x 3) for B subcategories in "Bacteria" & "Lice" tasks. N= 56 st. who answered B to both. C = 0.72

BACTERIA LICE	B 1	B 2	B 3	Total Lice
B 1	13 (6)	3 (7.42)	0 (2.57)	16
B 2	6 (9.37)	17 (11.60)	2 (4.01)	25
B 3	2 (5.62)	6 (6.96)	7 (2.4)	15
Total Bact.	21	26	9	N= 56

In order to compare the consistency in the use of accepted and alternative frameworks,the contingency coefficient C was calculated for A and B subcategories,drawing contingency tables (2 x 2) for A 1 & A 2, and for B 1 & B 2. As explained above B 3 was taken into account only for the "Bacteria" and "Lice" pair as shown in table 6. The contingency coefficient values for other tasks and categories can be seen in table 7.

Table 7. Contingency coefficient for accepted & alternative subcategories.

TASKS	A 1 & A 2		B 1 & B 2 (* & B 3)	
	N	C	N	C
Bacteria & Lice	48	0.31	56	* 0.72
Bacteria & Mice	63	0.12	32	0.25
Lice & Mice	42	0.41	35	0.15

It should be noted that, whereas subcategories B 1, B 2 and B 3 can be viewed as mutually exclusive, A 2 refers to answers incorporating part of the accepted explanation, so perhaps the correlation between the use of A 1 and A 2 does not mean the same as the correlation between the use of B subcategories. Considering this, and the number of students, results must be viewed as a first approach to the question.

As table 7 shows no conclusion can be drawn regarding the use of accepted or alternative frameworks. One thing we can say is that when students perceive two tasks as similar (as it is the case for "Bacteria" and "Lice" problems) they show a high degree of consistency in the use of frameworks. In all cases the positive correlation exists, this challenging the idea of these frameworks being "ad hoc" constructions produced by the students on presentation of the task.

6. GENDER-RELATED DIFFERENCES

Differences in performance in science topics and in professional choices between boys and girls have been reported among others by Deboer (1985) and Erickson & Erickson (1984). These differences are connected with a decrease among girls' positive attitudes towards science along school years, so no wonder that relatively few women choose scientific and technological subjects at the University level. Several actions have recently been proposed (Kahle 1985, Kelly 1986) to change this situation.

The study of gender-related differences in our case was only possible with part of the students, 76 (the first group). In the other group the anonymous answer sheets were collected in a way that did not allow to group them according to sex.

In order to check the differences in the numbers of girls and boys using accepted frameworks, Chi-square proof was tabulated for each task. Values in table 8 show that in all of the tasks, boys used the accepted framework in a higher proportion than girls. Moreover, in all the three tasks the figures of boys who used the accepted framework was higher than the ones who were not using it, whereas for girls the situation was the opposite. In all cases Chi-square values were signifiant to the level of 0.01.

Table 8. Different performances of girls & boys

Gender Categories Tasks	GIRLS Accept.	 Other	BOYS Accept.	 Other	χ^2
Bacteria	15	26	25	10	9.19
Lice	9	32	18	17	7.16
Mice	10	31	26	9	18.85

In other case that we have reported previously (Jiménez & Fernåndez 1987 a) among Secondary School students, no differences were found, so the subject needs further attention.

7. SUMMARY AND IMPLICATIONS

When faced with problems on natural selection, there was large percentage of Biology College students who used explanations regarding adaptation as a change of individuals that is passed on to offspring, and a number of them believed that "Limbs that are not used will finally disappear" or "suffer atrophy". Some of them explain evolutionary change with teleological ideas such as "in order to survive" or anthropomorphic ones.

Sometimes students used only one framework, but occasionally more than one was used, showing considerable confusion. The complexity of the topic and the need for sufficient time to develop carefully planned learning activities,ask for a reduction in spanish Secondary School syllabuses,as long programs force teachers and students into rote-memory methodology. We explored only the natural selection topic,but presumably the situation would be similar in other fields,as show Cañal & Rasilla work (1986) with photosynthese.

Proportions of students using accepted and alternative frameworks varied in different tasks contexts,but a degree of consistency existed between responses of the same individuals to different contexts,and although alternative ideas vary,a signifiant number of students used a relatively small number of them. This allows science teachers to prepare classroom material and activities taking into account alternative frameworks that happen to be used by a large range of students. We believe that one of the conditions for promoting conceptual change is for the teachers to pay attention to the students' ideas,but this hypothese needs further research to be proved.

The boys in this sample performed signifiantly better than the girls. This is consistent with findings by other authors and supports the idea that action need to be taken in order to enhance interest and participation of girls in Science.

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APPENDIX 1 The Tasks

1. "BACTERIA"

Resistence to Streptomycine in bacteria Escherichia coli is caused by an unfrequent mutation. Growing Escherichia coli in a medium containing Streptomycine,great numbers of resistant bacteria can be observed to grow.

Does Streptomycine change mutation tax?

How do you explain these results?

2. "LICE"

(From the newspaper "El País")

"Between 15 % and 20 % of School children are attacked by lice between Fall and Easter. The causes of recent epidemies are not known exactly,since hygienic care has improved in recent years,but everything seems to suggest that DDT and other available insecticide are not harmful to lice now"

How do you explain that insecticides caused harm to lice in the past and fail to do so now?

3. "MICE"

At the beginning of the century,a naturalist carried out an experiment consisting in cutting off the tails of mice along several generations,to see how the offspring came out.

a) What do you think would happen over 20 generations? Would they be born with tail or without? Explain it.

b) Do you think the result would be influenced by training an owl to catch mice by their tail,so the tailess ones would not be caught? Explain it.

APPENDIX 2

In the following excerpts from answers,students from the 1st group appear as 37,73...and students from the 2nd group as 37*,73*...

St.19 "Mice" "They would have tail,because a mouse is not so low a living being as a bacterium,and mutation would happen in a long term evolutionary process,after a long time."....B

St.27 "Bacteria" "Streptomycine in medium does active some gene and produces a change that affect the genome.".......B1

"Mice" "Cutting off tails does not affect to genes" A

St.57* "Bacteria" "With Streptomycine,changes in the organism would happen that over some generations are expressed in the genes"..B1

"Lice" "Lice are slowly adjusting to environment conditions (...) over some generations they adapt to the conditions in which they develop,in an environment with insecti-- cide,so they finally become resistant to it."..............B2

"Mice" "With tail.Is a change produced in the mouse's morphology,and does not in the least affect to genes. He would not have the information to be born without tail"...A

St.61* "Bacteria" "Mutant bacteria do resist,whereas the rest would die..."..A

"Lice" "If we apply insecticide to a louse,it would sensitize and it could die,but if we keep applying there would be a time when it becomes immune."..................B3

"Mice" "With tail(...) because genetic information is inalterable even when phenotype is modified."..............A

Primary School teacher education and alternative conceptions in science.

by

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Introduction

There is now a large body of literature describing studies of student s' knowledge of everyday phenomena and their language used to talk about it. This knowledge and language is often different from currently accepted science and is resistant to change even by formal instruction.There is evidence that student s' prior knowledge may inhibit the reception and understanding of ideas teachers intend to communicate in science lessons (Symington 1984)

This research has already begun to influence the nature and content of in-service courses for practising teachers (Jones 1984 , Biddulph & Osborne 1984) and also of pre-service courses for prospective teachers.This paper reports the author's attempt to sensitize pre-service teacher-students to the existence of children's prior knowledge of science and its implications for teaching and learning in the primary (elementary) school.

In planning the course the author intended to meet the needs of teacher-students as seen by him from a wider perspective of current thinking in science education as well as needs perceived by students themselves.As these sets of needs may not always match, student preferences and opinions were solicited about possible alternative course structures. Although the structure and content of the course for 1987 was of necessity already planned (and used the previous two years) some changes of emphasis were possible if the opinions expressed by students at the first session of the course were widely held.

The setting.

Most primary (elementary) pre-service teacher-students at the University of Tasmania are enrolled in a four-year Bachelor of Education program comprising courses in personal education (Mathematics, Science, Language, Social Science) ,general professional education (Philosophy, Psychology and Sociology in education) ,Curriculum & Teaching Studies in specific subject areas (eg C & TS Science) and school experience.

All students take C & TS Science 2 in their second year and become familiar with a range of available curriculum materials and ideas together with the stated rationale of each.The course attempts to meet a need, commonly expressed by students, 'to assemble many ideas' for science in order 'to survive' in the classroom. Students at this stage seem more concerned about their performance as a teacher than about children learning.

The course C & TS Science 4 ,to be described in this paper,was taken by students in their fourth year in 1987.It attempts to focus attention on what children actually learn and how they make sense of phenomena,in order to negate the belief that adequate science teaching results from just having a wide repertoire of "experiments" for children to do.

Course Structure and Content

The course commenced with a consideration of 'children's science', that is, children's conceptions about objects and events together with the language they use to articulate their ideas. An initial lecture described the results of some research studies and some of the methods used to probe children's understanding .A videotape record of the author's clinical interviews of some children, about common substances and their forms, was used to illustrate both the variation in people's understanding of common things and one method of probing personal meanings of words and explanations of events. Some of the consequences of this knowledge for teachers and its possible use as a strategic starting point for more meaningful learning were suggested. Students were required to follow up this introduction with a personal study of eight selected journal articles and reports of research into children's alternative frameworks of science knowledge.

The second major component of the course involved students working in pairs to take three one-hour sessions of science with small groups of children at a local primary school.They were required to explore the use of an interactive teaching approach in which children would be encouraged to interact **physically** with materials and engage in **dialogue** with each other and the teacher about those materials and related phenomena. A lesson outline for the first session was provided on the specified topic 'Common substances and forms of matter'. (Appendix 1)

Major aims related to an interactive approach.

Three major aims to guide the planning and execution of the teaching episodes were discussed during a course workshop session prior to the first school visit.These are as follows.

1. To help children extend their first-hand experience of the world of objects and events and to make better sense of their experience by exchanging views with others .
2. To foster the use and development of language, both spoken and written, as a means of generating personal knowledge on the assumption that the process of communicating is conducive to the refinement of one's knowledge .
3. To utilize chidren's prior knowledge, and their own language of talking about it, as the starting point for conversation and the generation of questions ,hypotheses and further activities for group exploration.

Key strategies and procedures to pursue these aims

Teachers should

1. use tangible materials to be manipulated at first hand by children,
2. have children respond to, describe and explain their first hand experiences in their own words and pictures (oral and written) ,
3. encourage children to listen to and understand alternative views of others through group sharing of observations,beliefs and expectations,
4. encourage the evaluation of different views of children,teachers and scientists,
5. have children generate questions which might be investigated using simple everyday materials.

Evaluation of teaching episodes.

For every episode one of each pair of teacher-students acted as the observer to record on audiotape the whole verbal interaction and to make written notes about other responses deemed significant.The roles of teacher and observer were exchanged on alternate visits but all planning and analysis was done in pairs .Transcribed records,notes and children's written work were to be the subject of reflection following each teaching episode in order to infer children's understanding of the topic and their meanings for words used.

A set of **guide questions** was given to assist students to write a succinct evaluation and to list ideas for subsequent lessons ready for the next planning session .Some of these were as follows.

1. What words and phrases did chidren use ? What do you believe they mean? How do they compare with your meanings ? with scientists meanings ?
2. How effective was your probing of meaning ? Did you pause long enough for children to comprehend you (and you them) and for them to complete their responses ? Did you show that you valued and accepted every genuine response ? Were any statements misinterpreted ? by whom ? why ? How might you conduct a more fruitful dialogue ?
3. What things were children most interested in ? What activities could be engaged in next time to clarify or challenge understanding and extend experience ?

Discussions immediately following the teaching episodes or at the whole group planning sessions provided a forum for students to share their experiences and to clarify matters about the approach or the topic.

All students were required to keep an organized clip file of lesson plans, observation records,evaluations and ideas for further activities on the topic.

Evaluation data and its collection

The opinions of teacher-students about alternative course structures and methods of delivery were obtained at the start and end of the course. Students were invited to respond to a list of propositions by indicating the extent of their agreement with each item. A five point scale ranging from strongly disagree to strongly agree was used .The list was preceded by a descriptive statement to set the propositions in a clearer context. (Figure 1)

At the end of the course students were also given a statement of five of the major objectives of the course and asked to indicate the extent to which they believed they had achieved each one. Free responses were also invited about each item and about the course generally. (Figure 2)

Student s'clip files and the lecturer's observation of teaching episodes were also used to evaluate the work.

Discussion.

The strong polarisation of opinion within the group on all the items in Figure 1 (except 1.4) is interesting in itself.

Although a variation was expected ,the roughly even pre-course distribution on most items was not. This situation is advantageous since there is likely to be a significant body of students who share a common belief with the course lecturer about what their needs are,thus making easier the group acceptance of a common purpose. More interesting, though,is the apparently stronger polarisation shown in the post-course data. For most items,students in the 'neither' category shifted opinion to the agree or disagree sides of the scale. A majority of students indicated a preference for a more detailed treatment of one or two topics and some expressed this strongly .(See items 1.1 &1.2) Similarly , although the group remains polarised on the issues, there appears to be a shift of preference away from a course of lecture-demonstrations (1.3) and of curriculum materials surveys (1.5) but towards a course involving work with small groups of children . (1.6)

In the absence of a control group the variation of preferences cannot readily be associated in a causal way with the science method course undertaken between the two opinionnaires. However the apparent shifts are consistent with written comments of many students about the course and its illuminating effects for them such that a causal association is likely .For example, in support of a more thorough in-depth focus some students expressed their new insight that the coverage of less content in their own teaching must be traded for a more effective communication of what is attempted. Consider the words of three students.

> The course "...has made me more aware of need to slow down the lesson content ...often to the detriment of realizing the set objectives."(E7.5)*
>
> "I must remember we are teaching children rather than science." (E11.4)
>
> "Sometimes I think we have been encouraged to neglect... (interactive methods) to get something concrete done, written down and handed in (by children) .Successs is often measured in these terms." (E2.4)

It is highly likely that these respondents have affirmed their initial preference for the more thorough approach or shifted preference to it.

One distinct advantage of the dialectical method fostered in the course is that what a teacher thinks she knows about a topic undergoes personal scrutiny as a by-product of her reflecting upon children's words and explanations.It should be noted that most of the teacher students have a very limited background of formal science so that the interactive teaching process can cause some considerable and benificial adjustment on their part. Some of the insights expressed about their personal knowledge illustrate this point and also indicate the levels of meaning being pondered.

> "I realized some of my own inadequacies as far as science was concerned eg. what do words like solid ,liquid and melt mean ?" (E11.1)
>
> "...in attempting to clarify children's understanding and the myriad of questions they raise in the course of a lesson I found my own understanding has not been deep enough or broad enough...eg. what is the difference between smoke,fumes, steam and gas ?" (E2.5)
>
> "Even some of the views I myself had vary from those of other adults, scientists and chidren...Children can make you more aware by introducing ideas (I had) previously considered to be general knowledge." (E5.1)

Course objectives.

Although one might expect a difference between actual achievement of course objectives and students' perceptions of their own achievement the percentages in Figure 2 are encouraging since the responses were made anonymously. The relatively large proportions in the greatest gain categories cannot be attributed to any attempt to encourage the lecturer to give better grades.

The majority of students believe they have made gains in the areas specified by the objectives.Most of those who reported 'no change' said they believed they already possessed the skills and dispositions specified. The perceived high gains for the objectives 1, 2 and 5 , concerned with the dialectical approach, are consistent with the possible shift of student opinion about the course work involving small group teaching (Fig 1,1.6) and the negative shifts in relation to the acquisition of curriculum knowledge (Fig 1,1.3 & 1.5).Some students expressed their insights about effective communication of science concepts in the following ways.

---

*Coding numbers of anonymous responses are shown in brackets

> "I wasn't aware that explanations are so different in the minds of children." (E10.1)
>
> "It seems so obvious now ,but ...I had never actually thought that when I used a term that children would understand it differently than the way it was meant." (E6.1)
>
> "I need to be much more careful to gain a true appreciation of what the children actually mean when talking to them... not to jump to conclusions about what they do understand and what they don't." (E9.1)
>
> "Don't just brush over a child's response which seems odd...rather I tend to probe it." (E8.5)

If students really have come to value more the dialectical method and to focus on the learner's understanding (Fig 2 , Objectives 3 and 4) they are more likely to reason that it is better to explore one science topic in depth than to skim superficially over many. Such reasoning may be reflected in the apparent shifts of opinion recorded in the first two items in the course structure opinionnaire. (Figure 1).
Consider the following responses in relation to this matter.

> "As the project progressed I realized more and more the implications ...in relation to teaching science. Unfortunately...there was not enough time in the course to thoroughly examine the issues that arose in the data collected through the tape...and observation notes." (E1.8)
>
> "Dialogue plays a larger role in science than I believed before the unit" (E25.3)

To employ an interactive approach requires a major shift from the didactic methods to convey meaning commonly observed in science lessons. Students expressed their difficulties in sustaining the method but appreciated the value to both teacher and children of persevering to achieve greater skill. For example ,

> "It has made me more aware of my questioning techniques and my own weaknesses in some areas of this." (E22.7)
>
> "It's very hard to reflect upon their language during a lesson...I valued the time after with the tape...and transcript...trying to analyze children's concepts." (E10.5)

Others commmented that the conscious decision to probe children's understanding helped them to refrain from using a lecture style (E8.2) yet some were observed to revert to such methods when they appeared to be confident of their own knowledge.On the other hand one student who was unsure of her own knowledge appears to have found a security in the method as she remarked,

> "I found the idea of talking at the same level with children and investigating science concepts we were both unsure of, very useful.The sense of discovery was heightened." (E6.2)
> and another wrote
>
> "This type of approach...provides confidence for teacher and student." (E26.2)

There is no doubt that many students feel secure about going to teach if they possess a thick file of ideas for activities, schemes of work and photo copies of one thing and another. However, much positive response has resulted from the exposure of a group of teacher-students to some of the current literature on children's learning in science,whilst at the same time having them gain personal experience of probing children's alternative views of everyday events in a small-group classroom setting .

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Figure 1 Student opinions about courses to prepare teachers of science.
(Pre & post course percentage histograms)*

Some courses focus on one or two science topics and provide teachers with fairly detailed background knowledge with practical experience of many activities suitable for children. Other courses provide a less detailed treatment of a wider selection of topics perhaps six or more. Within both types of course a variety of teaching approaches is possible.

Express your opinion on each of the following propositions in relation to an eight week course in C & Ts Science.

KEY
(The scale is 1= strongly disagree to 5= strongly agree)

1.1 The course should focus on one or two topics developed in detail in workshops.

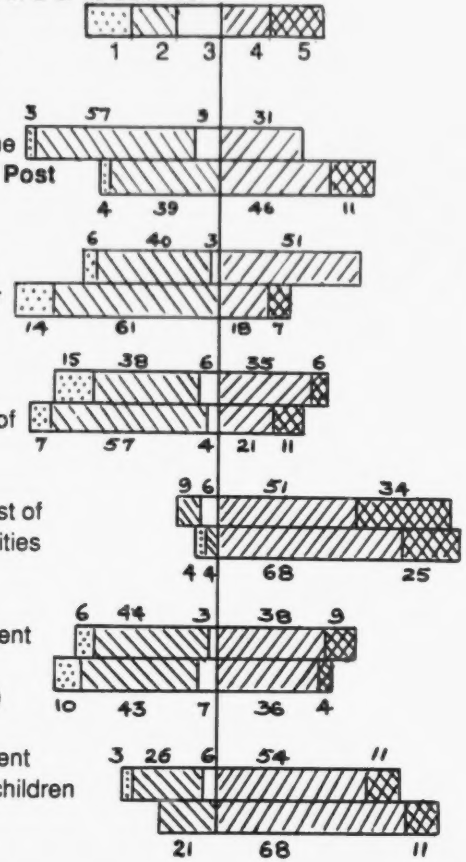
1.2 The course should treat many topics in less detail with fewer workshop activities.

1.3 The best approach is to use lectures with demonstrations of activities for children.

1.4 Students should engage in most of the suggested children's activities at first hand.

1.5 Most course time should be spent surveying science teaching resources.(texts,manuals,kits)

1.6 Most course time should be spent working with small groups of children to trial activities.



* Pre n=35 , Post n=28

Figure 2. Students' perceptions of their own achievement of some course objectives.
(Percentages shown for each category. n=29)

Objective 1.

That students will be more sensitive to the different ways children, adults and scientists describe and explain natural phenomena.

(a) no change	(b) more sensitive	(c) much more sensitive
7	62	31

Objective 2.

That students will develop further the skill of initiating and sustaining fruitful dialogue with children in order to clarify their mutual understanding of science concepts.

(a) no change	(b) development	(c) much development
10	66	24

Objective 3.

That students will value more the use of interactive dialogue as a major strategy in teaching science using concrete examples of phenomena.

(a) no change	(b) value more	(c) value much more
21	58	21

Objective 4.

That students will value more the approach of using children's knowledge,even if inconsistent with current science, as a starting point for teaching and for deciding what experiences to include and how to present them.

(a) no change	(b) value more	(c) value much more
14	62	24

Objective 5.

That students will be more inclined to accept a variety of children's responses for discussion and to listen carefully, reflecting upon the intended meaning of all language used .

(a) no change	(b) more reflective & accepting	(c) much more
14	55	31

Appendix 1. 'Describing & sorting common substances'

Aims. Lesson outline

1. To provide a context which fosters conversation about the properties and grouping of substances.(matter,stuff)
2. To determine the words children use to talk about matter, what they mean by them and how they are used.
3. To probe children's meanings of solid and liquid with a view to introducing what scientists mean by those terms.
4. To draw attention to the multiple useage of some words eg. three meanings of 'solid'.

Sorting activity-Small groups (6-8)

Two sets of samples per group :
ice, coin, chocolate, glass (jar), wax, iron nail, steel wire,
aluminium can //plasticene, cotton wool, aluminium foil,
steel wool, foam plastic, jelly lolly, rubber eraser// sand,
sugar, salt, honey (runny), cooking oil, kerosene, water.

Explain that you believe they know a lot about these samples of stuff from around the home but you want them to observe each one carefully,to handle and describe them and talk about how they could be sorted into groups.

Either have children write the names of each sample on slips of paper (3 x 5 cm) to arrange in classes OR physically move the samples into the chosen classes.

Engage in dialogue and probe meanings for words and explanations as children go about the work.

Have children compare different sorting systems, identifying similarities and differences, suggesting reasons .

Record the class names and grouping criteria.

Arrange samples in a chemist's grouping (solid-liquid) and talk about the criteria ,"rules" ,for this arrangement with reference to children's use of these words .

Whole class conclusion

Solicit feedback from groups. What have you found out ? Did you all sort things the same way ? Why ? Who sorted plasticene with honey ? Can you pour honey ?

Discuss examples of 'solid' things and things which are in the chemist's class of solids to bring out different meanings.

List children's questions about substances which might be investigated on future occasions. Further stimulus might arise from questions such as 'How do they make chocolate into different shapes ?' 'Are jellies made the same way ?'

INTERRELATED MATH CONCEPTS: UNDERGRADUATE TEACHER EDUCATION STUDENTS' PERSPECTIVES

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Introduction

Teacher education programs often follow a similar pattern in the area of mathematics education for those students who are not mathematics majors. This pattern includes a course or courses in mathematics content, usually number systems, theory, and geometry which is followed by a course in methodology.

These prerequisite mathematical content courses may not necessarily guarantee that students have a firm understanding of mathematics for the elementary school which they then need to learn how to teach to children of a variety of abilities. The variety in the backgrounds of the teacher education majors from both their abilities to master the content of the mathematics courses and the alternate courses which may be substituted for the education major transferring from another program or another institution is a basic challenge to the professor of the mathematics education course.

The resolution of this concern is not to condemn the professors or nature of the mathematics courses taken by the students, an easy trap into which one might fall, but, instead, to attempt to provide students with a synthesizing experience as they begin their studies of the methods of teaching elementary school mathematics.

Background to the Learning Tasks

It is important to examine the prerequisites to the learning tasks in both the mathematics content course or courses and the methods course. We may best examine these through Ausubel's (1968) learning variables. First, the affective-social and then the cognitive categories.

A. Affective-Social Categories

The affective-social categories include personal motivation, individual personality, the classroom climate and interaction in which past learning has taken place, and teaching styles to which the teacher education students have been exposed.

It has been noted that the motivating drive for students to learn is both a function of previous successful experiences and anticipation of future satisfying consequences (Ausubel, 1968). The question of motivation may be related to math attitude or even math anxiety. Interviews with students indicate that this does affect their motivation to take the mathematics content courses but not necessarily the course in teaching methodology. In fact some research seems to indicate that the motivating drive to teach math well is neither related to successful nor unsuccessful previous experiences which may have formed the basis for attitudes or anxieties.

> ...it should be emphasized that one cannot assume that all teachers who disliked mathematics as students, or even those categorized as math-anxious, dislike teaching mathematics. Many, in fact, seem eager to break the cycle of poor attitudes engendering poor attitudes and are determined to provide their pupils with positive experiences in learning mathematics. (Widmer & Chavez, 1982, p 276).

Individual personality characteristics are often reflected in the comments students with whom I work make when they are asked the reasons for their choice of a career in teaching. These include liking children, wanting to help others, wanting to make education better for children today than it was for them, and enjoying the social community of the school.

These outgoing, social characteristics do not seem to affect their attitude toward or commitment to specific courses in the curriculum. If they have made a personal commitment to their career goal they generally have the motivation to work to succeed in their required courses.

The learning environments and teaching styles that the college students have experienced in the past as noted earlier may have both positive and negative effects on their attitudes toward the general teacher education curriculum and the specific courses in both mathematics content and methodology.

B. Cognitive Categories

The cognitive factors in learning include: readiness, intellectual ability, and cognitive structure.

In view of the fact that college students are generally mature adults we usually assume that they are ready, that they possess the "...cognitive processing equipment or capacity for coping with the demands of a specified cognitive learning task." (Ausubel, 1968, 176).

We believe that they have the intellectual capability to succeed in college. This is based on the fact that they are usually at least at the junior or senior level in good academic standing when they take these courses. The question of intellectual readiness is given. The variety of intellectual ability seems to be adequate for the task of both learning about how the mathematical systems work and learning how to teach others about these systems.

The question must then be asked: "Do the teacher education students have the cognitive structure necessary to use the mathematics content that they learn either through receptive or discovery learning in the mathematics department? Raising this question is not an indictment of the teaching and learning in the course on mathematics content. Instead, it is a question which we must ask ourselves as mathematics teacher educators as we begin teaching each new group of students.

Statement of the Challenge

If the affective-social categories of learning variables and the readiness and intellectual functioning levels of our teacher education students are adequate as they generally seem to be, how may we provide meaning to the mathematics content as we begin a course in mathematics teaching methodology?

One Study of the Challenge

The undergraduate students seeking certification in early childhood (kindergarten), elementary (1-6 grades) and educationally handicapped (K-12 grades) at Cleveland State University take their mathematics methods course in the College of Education following a two quarter sequence of mathematics content courses taken in the mathematics department of the College of Arts and Sciences.

It is proposed that if students lack the cognitive structure necessary to use the mathematics content that they have learned in the mathematics departments' course(s) it is essential for us to help them to develop this structure.

For most of the sixty students in the mathematics methods course this past spring quarter, 1987, the idea of taking their personal ideas about various fundamental mathematics concepts and attempting to create a cognitive map of them was a real challenge.

As has been noted "Concept mapping is a technique for externalizing concepts and propositions." (Novak & Gowin, 1984, p. 17). The students were able to gain some perspective on the meaning of these math concepts and their relationship to mathematics education through this technique.

The specific challenge issued to each student was to take the following twelve concepts labelled in separate boxes on a sheet of paper, cut them apart, and arrange them into a map while at the same time adding five other mathematical concepts, for a total of seventeen. [The general outline for presentation of this technique is detailed specifically in Novak and Gowin (1984) on pages 32 through 34.]

Addition
Subtraction
Multiplication
Division
Zero
Negative Integers
Rational Numbers
Irrational Numbers
Real Numbers
Whole Numbers
Counting Numbers
Positive Integers

The college students were in general intrigued by the idea of thinking about their thinking but at the same time found the task to be a genuine challenge. They were assigned to begin the task in class following the introduction and were encouraged to discuss it with colleagues, friends and family. They each accomplished their version of a concept map and submitted it within one to five class periods later.

General Results

Over the past few years there has been a great deal of research about thinking in the school classroom. This was an opportunity to apply what we have learned to a teacher education setting. It has been said that

> ...teachers influence students by causing them to think and behave in particular ways during teaching. These mediating events, in turn, may lead to changes in outcome variables. Hence, the effects of teaching on learning may be mediated by students' behaviors and cognitive processing during instruction. (Winne & Marx, 1982, p. 495)

There is no statistically measured outcome to this pilot study of concept mapping in a mathematics methods course but there were a number of interesting things which happened.

First, this was a visual means to assess the understandings and misconceptions which students had about these basic math concepts and their interrelationships to one another, with the importance placed on the gestalt. Students who had done well in the prerequisite mathematic content courses as measured by their grades were challenged to see the relationships among both the first twelve given concepts and the subsequent five which they selected. Students were most often heard to complain that the linkages were difficult to identify.

The creation of these cognitive maps thus provided a natural means to discuss and define how math concepts are related to one another and how we might teach children about them in order to prevent the development of misconceptions.

It was of particular interest to students to hear about how others thought through this process. Thinking about their own thinking seemed to help them gain insights into how children think about and learn mathematics.

Further Specifics of the Study

In order to gain additional, specific insights into the usefulness of this teaching strategy five students volunteered to meet with me individually to discuss the task. All students were assured in writing that their participation in this activity had no effect on the outcome of the course. In this way it was hoped that the results of the interviews would be genuine.

Peterson and Swing (1982) noted

> ...that interviewing students about their thought processes can provide rich information beyond what can be obtained by merely observing their behavior in the classroom. (p. 489)

Although their work applied to elementary school settings, similar outcomes were apparent in this work with teacher education students.

Profiles of the Students Interviewed

Student One:

> female; 35 years old; post-degree student who holds a degree in French received 13 years ago; cumulative grade point average: 3.71; earned an A in each of the prerequisite mathematics content courses designed for teacher education majors which were taken here; final grade in math methods: B.

Student Two:

female; 46 years old; undergraduate; cumulative grade point average: 3.59; earned first a U and then an S in basic algebra, earned an A in the first of the math concepts courses for liberal arts majors and a C in the second of these courses, earned a B in each of the prerequisite mathematics content courses taken here; final grade in math methods: A-.

Student Three:

female; 22 years old; undergraduate; cumulative grade point average: 2.93; earned a D in each of the prerequisite mathematics content courses taken here; final grade in math methods: A.

Student Four:

female; 44 years old; post-degree student who received a degree in 1965; cumulative grade point average: 4.00; earned an A in each of the prerequisite mathematics content courses taken here; final grade in math methods: A.

Student Five:

female; 41 years old; undergraduate; cumulative grade point average: 2.89; earned a C in intermediate algebra, earned an A in each of the prerequisite mathematics content courses taken here; final grade in math methods: A.

As may be noted, with the exception that all five students were women they had little in common and represented the range of students who are in our teacher education program [older (average age 29), female, varying abilities and backgrounds in mathematics content].

Interview Questions

Each student was asked to respond to the following questions.

1. Tell me how you went about trying to figure out the interrelationship of these different terms in mathematics and their linkages.

2. You had the assignment to add five additional concepts. How did you decide to use these five (pointing to the ones on the student's map)?
3. Had you ever done anything like this before?
4. (If YES to the above) How had you used it in other subjects?
5. (If YES in #3) Have you tried using it with children at any time?
6. Sometimes people tell me that the thing that's hardest about this is figuring out what words to use for the linkages. Was this an easy task? a difficult task? How did you decide on these words and/or phrases?
7. Is there anything more you'd like me to know about how you did this or how you reacted to doing this in mathematics?
8. Do you think that it would be a good idea to require this activity at the beginning of every quarter in math methods in order to help people synthesize their previous work in mathematics? Why?

Summary of Answers

All of the students said that they went back to either the textbook or their notes for the math content courses in order to refresh their memories about the meaning of the terms. They used this as the basis of deciding about interrelationships. Several mentioned that this helped them see how the math content which they'll be teaching could be related for children. Most noted that they liked the concepts on separate slips of paper as it helped them to move the slips around in order to come to the final map which was then copied onto a sheet of paper.

The additional terms selected by the students were either those with which they were familiar and could easily recall or those they noted while browsing through notes or books.

Two students noted that they had been doing "webs" in language arts (in which they put a central theme on paper and then noted related ideas to teach the theme around it in the form of a spider web). They thought there was some similarity to this activity. One noted that she had used a web with a student in her field experience classroom in order to help her see how things in a science lesson related to one another from a central concept on out.

All of the students said that they had difficulty deciding on linkage words. Several said they seemed to be "stuck with" just a few terms and were unable to think of more.

It was generally agreed that this is a good activity to use at the beginning of the methods course as it was

> ...terrific for organization, classification...it brought up some questions to me...you could really go into an in-depth thinking activity with this.
> (Student Two)

> ...you see how everything all comes together and how all these little pieces go together as a whole...Because when you see the chapter titles, everything isn't as clear as to how everything connects as you can see it in the map like this.
> (Student Four)

> You would have some overview of numbers and how they relate...we could...gain insights from another person's perspective...(by sharing concept maps)
> (Student Five)

> I mean when you first showed it to us, I thought you know how does this apply? And please don't tell me I have to do rational and irrational numbers again. But, from when I did them I don't remember them. So it kind of refreshed your memory again on what they are, how do things relate and it gets you kind of into the mathematics mode I think - to get you back into knowing all these definitions when you use divisor and dividend as you look at where division is going to go you start thinking about those words again. It starts washing back into your mind.
> (Student Three)

Conclusions

As you may note by looking at four of these concept maps, the students demonstrated that they had a variety of misconceptions about the interrelationships among math concepts. [Insert Students One through Four concept maps about here.] These misconceptions were discussed in large and small groups and individually in order to clarify the concepts and their relationships with one another. They were a focus for our thoughts.

They enabled the students to see that there is more than one right way to look at interrelationships. The acceptance of this variety added to the students understanding that it is important to accept the thinking of the students whom they will be teaching.

In addition, it is important to think about the process of thinking. Concept mapping is a teaching strategy which encourages college students to do just that as they integrate their study of mathematic concepts with the methods for teaching them to children in school.

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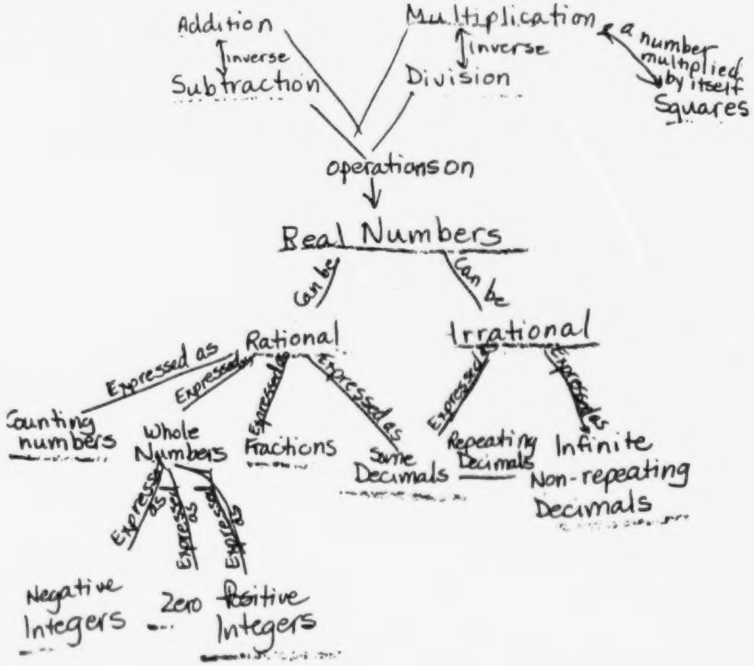
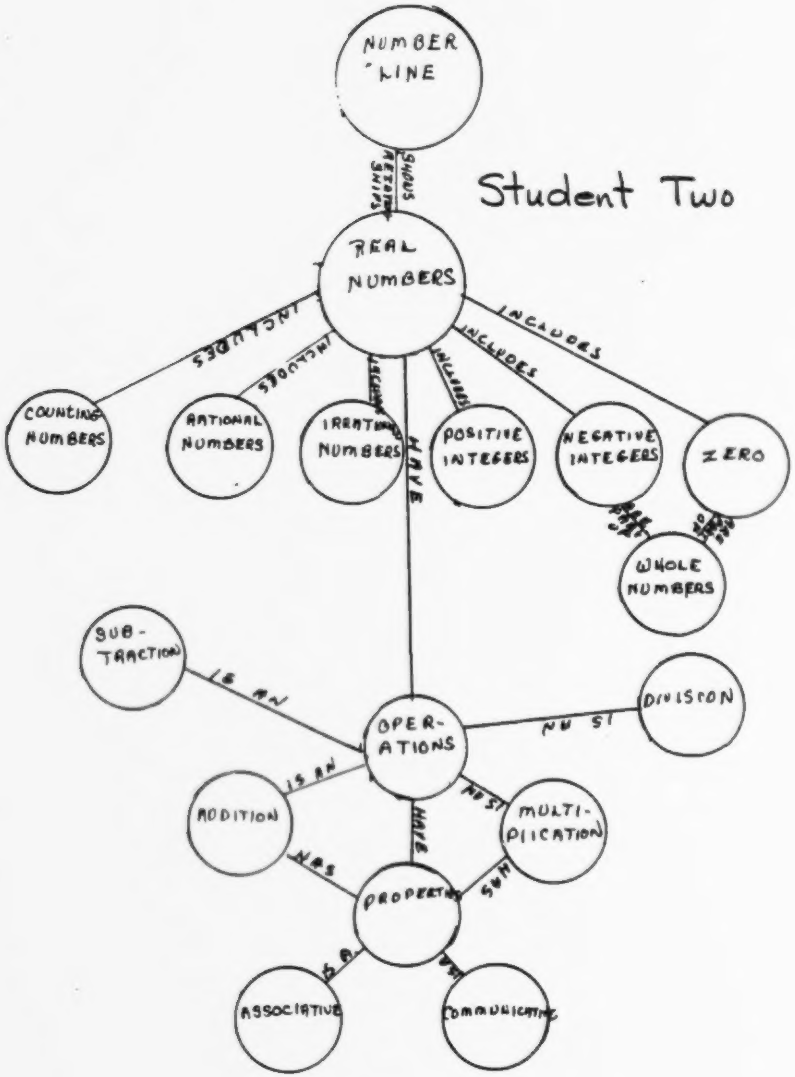
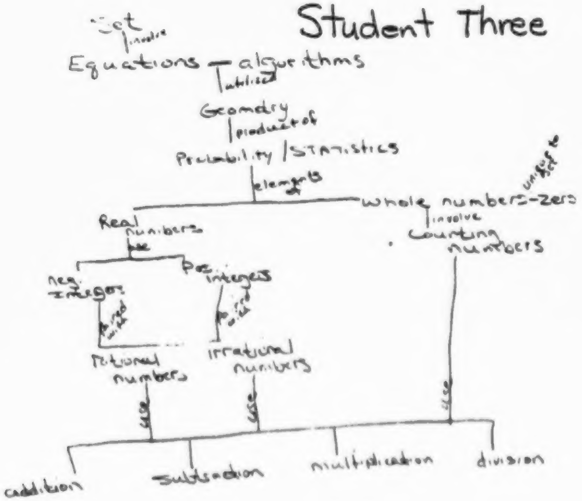

Addition
inverse
Subtraction
Multiplication
inverse
Division
a number multiplied by itself
Squares
operations on
Real Numbers
Can be
Can be
Rational
Irrational
Expressed as
Expressed as
Expressed as
Expressed as
Expressed as
Expressed as
Counting numbers
Whole Numbers
Fractions
Some Decimals
Repeating Decimals
Infinite Non-repeating Decimals
Expressed as
Expressed as
Expressed as
Negative Integers
Zero
~~Positive~~ Integers

Student One



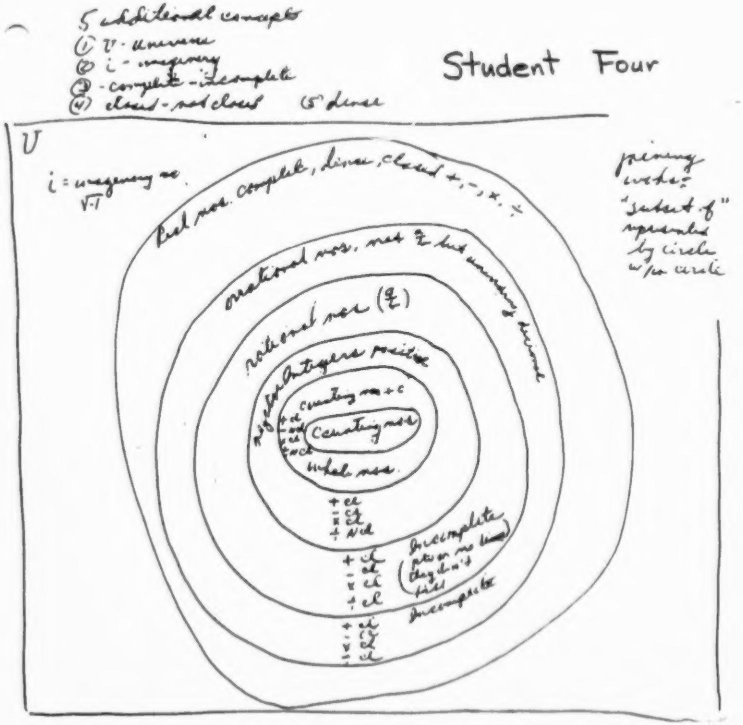
Student Two

NUMBER LINE
SHOWS RELATIONSHIPS
REAL NUMBERS
INCLUDES
INCLUDES
INCLUDES
INCLUDES
INCLUDES
INCLUDES
COUNTING NUMBERS
RATIONAL NUMBERS
IRRATIONAL NUMBERS
POSITIVE INTEGERS
NEGATIVE INTEGERS
ZERO
ARE PART OF
ARE PART OF
WHOLE NUMBERS
HAVE
SUB-TRACTION
IS AN
OPER-ATIONS
IS AN
MUST
MUST
DIVISION
ADDITION
MULTI-PLICATION
HAVE
HAS
HAS
PROPERTIES
ARE
ARE
ASSOCIATIVE
COMMUNICATIVE



Student Three

Set
involve
Equations — algorithms
utilized
Geometry
product of
Probability / STATISTICS
elements of
Real numbers
whole numbers-zero
unique to set
involve
Counting numbers
are
neg. integers
pos. integers
paired with
paired with
rational numbers
irrational numbers
use
use
use
addition
subtraction
multiplication
division



Student Four

5 additional concepts
① U - universe
② i - imaginary
③ - complete - incomplete
④ closed - not closed ⑤ dense
U
i = imaginary no. √-1
Real nos. complete, dense, closed +, −, ×, ÷
irrational nos. not a/b but unending decimal
rational nos. (a/b)
negative integers positive
counting nos. + 0
Counting nos.
whole nos.
+ cl
− cl
× cl
÷ Ncl
+ cl
− cl
× cl
÷ Ncl
+ cl
− cl
× cl
÷ cl
Incomplete (points on no. line they don't fill)
Incomplete
+ cl
− cl
× cl
÷ cl
joining words: "subset of" represented by circle w/in circle

SYMBOL USE AND CONCEPT DEVELOPMENT IN GENETIC ENGINEERING

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INTRODUCTION

The field of recombinant DNA (rec. DNA) technology, commonly known as 'genetic engineering' or 'genetic technology' is one that has a central place in genetics courses at college level. Aspects of rec. DNA technology are also incorporated into biology courses at high school level. The inclusion in the curriculum of details of the technology and of its actual and potential applications in fields such as medicine, agriculture, and industry is justified on the bases of the relevance and the impact of applications to everyday life, and of the consequent personal, social, and ethical considerations.

Unlike many other technologies, the procedures of rec. DNA technology are not complex. Constraints on the use of rec. DNA technology currently do and will in future arise, not from technical limitations of the procedures per se, but rather from the ethical, economic, and social considerations engendered by potential uses of the technology. It is important that, as part of their studies in genetics, learners be made aware of the relative simplicity of the technology that underlies the complexity of the ethical and social issues associated with its application (Figure 1).

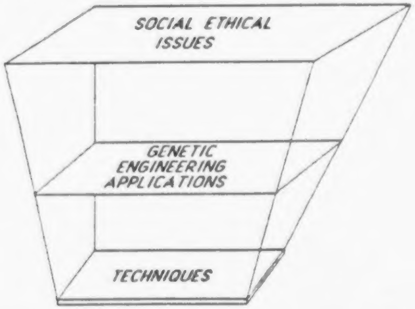

Figure 1: A schematic representation to show that genetic engineering applications depend on the availability of certain techniques. Social and ethical issues arise as a consequence of the availability of the applications.

The identification and representation of the so-called substantive structures of an area of study can provide an appropriate basis for decisions relating to curriculum development, instructional design, and evaluation of student learning in that area. Substantive structures are networks of meaning comprising relevant concepts and their specific relationships; these structures may be represented in a number of ways. One means of representing substantive structures is the use of active structural networks (Norman et al. 1975), and this is one of several methods discussed by Stewart (1980) and Finlay and Stewart (1982). Active structural networks have been used by Stewart and van Kirk (1981) to represent part of the substantive structures of genetics.

This paper reports on the identification of the substantive structures of rec. DNA technology and their representation by means of active structural networks. The development of these networks was undertaken in order to guide the design and development of one computer-based resource, Genetic Engineer's Toolbox (Kinnear 1986). The paper also provides a preliminary report of an on-going study of learning outcomes in a small group of non-biology non-science students undertaking activities involving use of this resource. Since the study was concerned principally with the initial establishment of a conceptual framework, coverage is restricted to the early teaching sessions only. The study draws on one of Brown's (1982) suggested strategies for understanding and attempting to facilitate conceptual development and change in learners, namely, to identify and describe qualitative differences between students. In addition, because of the small size of the group, it was possible to follow, through the use of concept mapping, the development of conceptual frameworks in students.

The report is descriptive in nature and is directed to generating some insight into and understanding of problems associated with facilitation of meaningful learning and the establishment of conceptual frameworks in a situation in which the students' prior knowledge of the subject matter was expected to be limited, in which the learning was intended to provide a background to the major topic of study, in which the time available to provide this background was constrained, and in which a major resource for the learning activities was computer-based.

The questions addressed in this study included:

- What prior knowledge of rec. DNA technology did the students bring to the learning activities?
- What attitudes did students hold with regard to the techniques and applications of rec. DNA technology?

- What outcomes - cognitive and affective - were associated with the preliminary learning activities?

In addition, the paper briefly considers the role of visual symbols and metaphors in concept development.

MATERIALS AND METHODS

Active structural network

Development of active structural networks to represent the substantive structures of rec. DNA technology involved the identification of relevant concepts and of the specific propositions that convey their meaningful relationships. These components were incorporated into active structural networks (Norman et al. 1975). Active structural networks representing some of the components of rec. DNA technology are shown in Appendix A (Figures A1 to A6).

The computer-based resource

The knowledge content and modular structure of the computer-based resource, Genetic Engineer's Toolbox, was guided and informed in its developmental phases by the active structural networks.

The program incorporates use of visual symbols to denote key causative concepts, namely the enzymic "tools" used in rec. DNA technology. The symbols may be classified as metaphors. The information embedded in these symbols varies; in some cases, the symbol provides a cue to the verbal label denoted by the tool, in other cases, the form of the symbol provides a cue, by analogy, to the learner concerning the function of the tool. The symbols used in the program are shown in Figure 2 which is a screen display from the program. It may be seen that symbols denoting the enzymes: ligase, polymerase, and reverse transcriptase incorporate a relevant letter symbol. The scissors symbol denoting restriction enzymes, the 'Pacman' symbol denoting nuclease, and the bow component of ligase, denote the respective functions of these enzyme, namely, cutting, trimming, and joining. Similarly, the glasses symbol for gene probes denote their function in locating specific strands of nucleic acids.

The student group

The students who participated in the study were a small group (N = 7) of mature-age elementary teachers who had previously completed a diploma-level teaching qualification. The students were currently completing a part-time study program leading to a bachelor-level education qualification. The students were enrolled in an elective unit entitled '**Contemporary Issues in Biology**' and were scheduled to engage in a module on social and ethical issues relating to the so-called 'new genetics'. The learning activities that the students undertook were directed towards development of a basic understanding of the procedures of rec. DNA technology, sufficient to provide them with a background for discussion of issues relating to applications of the technology.

No student in the group was either a science or a biology major, nor had any student previously undertaken any formal studies at school or college level of rec. DNA technology.

Throughout this study, the term 'genetic engineering' was used in association with the term 'recombinant DNA technology' because the former is the more common in everyday use.

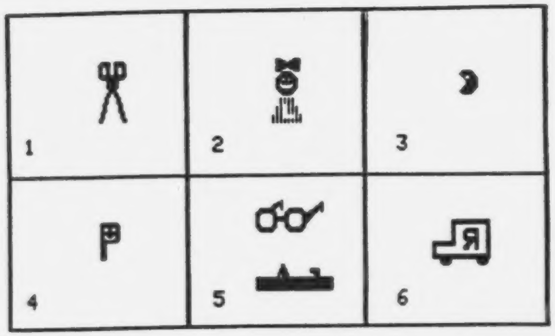

Figure 2: Screen display from GENETIC ENGINEER'S TOOLBOX showing graphic images used to symbolise some enzymes and other agents used in recombinant DNA technology.

Prior knowledge

In an introductory class (session 1), aspects of the students' prior knowledge of and attitudes to rec. DNA technology were explored by means of a number of tools including a questionnaire, a free recall task, a prompted recall task, and a task to measure the students' knowledge of and attitudes to selected procedures and applications of rec. DNA technology.

In the **questionnaire**, students were asked to report whether they had heard of 'genetic engineering' or 'recombinant DNA technology', and if so, to identify the information source from a list of possible sources. Sources, additional to those on the list, could be identified.

Students were also requested to indicate by marking on a five-point scale, their perceived views of the simplicity/complexity of the techniques of rec. DNA technology and of the desirability /undesirability of its uses. This initial questionnaire contained no information about genetic engineering, so that students who were unaware of the technique or who thought it synonymous with other techniques, such as in vitro fertilisation or amniocentesis, gained no insight from the wording of the questionnaire.

In the **free recall task**, students were asked to define 'genetic engineering' in their own words.

For the **prompted response task**, students were given an abridged version of a newspaper article outlining some of the techniques of genetic engineering. Students had a five-minute reading period, and were then asked to identify two key ideas about genetic engineering from the article. Students had access to the article during this task. Students were also requested to identify from the article both terms that they understood and terms that they did not understand.

For the **perceived knowledge and attitude task**, students were presented with a list of thirteen items that included both procedures and applications of genetic engineering (Appendix C). Students were asked to indicate their perceived knowledge of the feasibility status of each item by checking one of three responses, namely, 'possible' (actual or potential); 'impossible'; 'don't know'. Students were also asked to indicate their attitude to each item by checking one of three possible responses, namely, 'should be done'; 'should NOT be done'; 'no opinion' .

The final task in the introductory session was the **re-definition** by students in their own words of 'genetic engineering'. Students no longer had access to their earlier definitions. However, this second definition was given after students had been incidentally exposed to information about aspects of rec. DNA technology as part of earlier tasks .

The learning session

In session 2, the students participated in a learning session that involved use of the 'Genetic Engineer's Toolbox' microcomputer program (Kinnear 1986), used under instructor control in a demonstration mode to the group of students. A large color screen monitor was used to display the program. Subsequent activities in which the program was used under student control for directed exploration were also undertaken, but these are not the subject of this paper. Two major areas of content were presented to students, namely the structure of DNA, and tools for the manipulation of DNA, in particular, restriction enzymes, ligase, nuclease, and reverse transcriptase.

Student responses to aspects of the computer program, in particular the use of graphic images to denote tools for the manipulation of DNA, were sought through a short questionnaire given at the completion of the teaching session.

Concept maps

In attempting to gain some insight to the early development of conceptual frameworks dealing with rec. DNA technology, concept mapping was used. Since the students had had no prior experience with this technique, they were shown a sample concept map, and the procedure for its generation was explained. Students then practised the technique, using a supplied list of concepts relating to characteristics of domestic animals. All students indicated their understanding of the process.

For the study, students completed three concept maps: one map dealing with the structure of DNA, the other two maps dealing with the procedures of rec. DNA technology. In every case, students were supplied with a list of concepts. However, it was indicated that other concepts could be added. For the DNA map, 17 concepts were provided, for the two technology maps, the same list of 24 concepts was provided, and additional for the last map, the graphic symbols were also made available. It should be noted that these graphic symbols were redundant since the verbal labels for the symbols were included in the list of 24 concepts. The students were not directed to use these graphic symbols. Concept labels were supplied printed on cellulose acetate strips. Students compiled their maps on large acetate sheets. This strategy was chosen to give students ease of handling, positioning and re-positioning of the concept labels which were then affixed using transparent tape. Propositions were added using water-soluble pens so that alterations could be readily made.

Information from tasks other than concept maps was used to gain insight to students' initial understanding of rec. DNA technology. This decision was made because the investigators did not wish to confound students by confronting them early in the first session with a list of concepts that would be expected to be unfamiliar to them.

RESULTS AND DISCUSSION

Prior knowledge :

The findings regarding the prior knowledge of the students as identified through several tasks are described below.

INITIAL QUESTIONNAIRE

Because the initial questionnaire contained no information about genetic engineering, the students' responses relate to their own concept of genetic engineering. Six of the seven students reported that they had heard of genetic engineering. Figure 4 shows the sources of information identified by these six students. It is reasonable to conclude that they had fashioned their explanatory schemata relating to rec. DNA technology from information from these sources. However, further questioning indicated that some students equated rec. DNA technology with techniques such as amniocentesis, in vitro fertilisation, and cloning (in the sense of the film, 'The Boys from Brazil' or the novel, 'In His Image').

SOURCE OF INFORMATION	NO. OF STUDENTS
Newspaper article(s)	5
TV program(s)	5
School/College classes	2*
Discussion with doctor	0
Magazine article(s)	4
Conversation with friends	3
Conversation with family members	3
Film(s)	2*
First-hand personal experience	1*
Radio	2
Other	0

Figure 4. Sources of information from which students claimed to have heard about their conception of genetic engineering. Responses denoted by an asterisk (*) were found not to relate to rec. DNA technology.

FREE-RECALL TASK

The initial free-recall definitions of genetic engineering given by the students are shown in Figure 5 below. The definitions given after student had completed all the prior knowledge items is shown in parentheses.

Student S7 was the one person who reported initially as not having heard of rec. DNA technology or genetic engineering. The initial free-recall definitions indicate that students held blurred or inaccurate concepts of genetic engineering and its boundaries. The conceptual framework of recombinant DNA technology held by student S3 apparently encompasses the technology of in vitro fertilisation.

Many of the initial definitions contain reference to a purpose or outcome of genetic engineering, and many include reference to genes, but not to DNA specifically. In contrast, all later definitions refer to DNA and focus on elements of the techniques rather than outcomes. This shift in definitions given by the students is presumably an effect of the reading of the newspaper article which provided information about DNA, and confirms that content embedded in an item may affect the variable that the item is seeking to measure or describe. . It is reasonable to suggest that the changes in definitions reflect changes in conceptual frameworks with the students constructing new meanings and modifying their original conceptual frameworks. This change is not unexpected since the students did not have frameworks based on early and extensive prior experiences of rec. DNA technology, and it has been proposed (Driver and Erickson 1983) that conceptual frameworks will be more or less labile depending on the extent of early sensory and linguistic experiences.

Many authors (for example, Claxton 1982, cited in Erickson 1982) have recognised that learners' personal schemata for a phenomenon are fashioned and re-fashioned from various inputs including

direct and personal 'real-world' encounters ('gut' science),
informal information transmitted in domestic settings or from media sources ('lay' science), and
structured activities in formal learning settings ('school' science).

Not unexpectedly, this group of students had had no real-world encounters with rec. DNA technology or its applications; nor had the students had any previous involvement in formal learning situation dealing with genetic technology. Any prior knowledge and understanding of rec. DNA technology that students brought to this study was based solely on informal inputs from media and other sources. This situation provides a contrast to learners' understanding of other phenomena, for example, mechanics and

S1 'Individual cell make up of a person. Also altering the cells in question.'
('Process of separating, analysing and synthesising the DNA of a human cell')

S2 'Using genes for a specific purpose and trying to isolate them for this purpose.'
('Joining of different DNA particles through slicing and cleaving.)

S3 'Genetic engineering is, I believe, the manipulation of nature by man. I do not see this as being a bad thing, but rather a progressive technique used by man to create more productive food sources and also to discover the beginning of human existence, and consequently use these technologies for assisting infertile people.'
('The manipulation of DNA from cells by man.')

S4 'Organising or arranging genes such that fetuses display designed or pre-determined characteristics for a variety of reasons.'
('Using recombinant DNA to determine or alter heredity and other uses such as preventing disease.')

S5 'Selecting sets of genes for a particular purpose - to give birth to a particular individual of desired qualities.'
('The process of splitting DNA molecules and rearranging them by joining them with other similar split molecules.')

S6 'It is where a living thing is brought into the world with a specific purpose in mind and that in the producing of this living thing specific traits are fostered.'
('The changing & position of the make-up of the 2 coils in DNA.')

S7 'I would think that it has to do with reorganising genes to suit a desirable outcome.'
('Genetic engineering is the process whereby DNA can be altered to cause a different genetic structure by replacement to a different part of the cell, by adding another DNA substance to it or by removal of a section of it.')

Figure 5. Initial free-recall definitions of genetic engineering or rec. DNA technology given by the students. Definitions given after the students had completed additional tasks that included some content matter are shown in parentheses.

temperature, where their conceptual frameworks derive from personal encounters, from informal inputs, as well as from formal learning situations.

The initial questionnaire also indicated that, at a global level, students viewed the techniques involved in rec. DNA technology as more complicated than simple, and the uses of the technology as more desirable than undesirable (Figure 6). These views, however, relate to 'genetic engineering' as initially conceptualised and defined by the students.

Genetic engineering involves procedures that are:

```
                                              X
                                  X           X
very        ____________X____     X_   X_     X        very
simple   1        2        3      4           5    complicated
```

On the whole, the uses of genetic engineering are:

```
                         X
               X         X
desirable  X____  X_____  X__X_________   undesirable
           1      2       3     4      5
```

Figure 6. Summary of student responses, at a general level, to aspects of the techniques and the applications of rec. DNA technology.

PROMPTED RESPONSE TASK

From their reading of the abridged newspaper article, students each identified two key ideas. From the total of fourteen statements generated by the students, eight different concepts were expressed. The most common major idea, identified by five students, was that DNA can be manipulated; another common major idea, identified by four students, was that DNA can be transferred from one cell to another. Only one statement related to a specific aspect of the technology, namely, the joining of cut pieces of DNA.

Overall, the students listed a large number of terms from the newspaper article that they either understood or did not understand. Of the scientific terms, those identified by all of the students as understood included: nucleus, cell, and bacteria, while those identified by all or most of the students as not understood included: plasmid, recombinant DNA, and restriction enzyme.

PRIOR KNOWLEDGE OF AND ATTITUDES TO REC. DNA TECHNOLOGY

In response to one multiple choice item concerning the identity of the material of which DNA, the genetic material is made, only one student selected 'nucleotides'. The majority opinion selected by four students was 'protein'. In response to one True/False item, five of the seven students indicated as true the following statement: 'The genetic material in seaweed, frogs, cats, gum trees, and humans is made of the same chemical substance'.

With regard to perceived knowledge of the techniques and of the applications of genetic engineering (Appendix B), more than half of the student responses fell into the 'don't know' category. For all items , except items T3, T4, A2, and A5, the majority response was 'don't know' This was in contrast to the reported attitudes where the majority of responses were definite, either 'should be done' or 'should not be done'. A striking difference was seen in reported attitutes to applications compared with reported attitudes to applications - overall, there was a more positive attitude to applications, while there was a more negative attitude, expressed as 'should not be done', to rec. DNA techniques. The finding in this small sample is in accord with a survey of two larger group of students (Kinnear and Gleeson 1987) that similarly reported more definite attitudes to than knowledge of techniques and applications of rec. DNA technology. This finding confirms that students' conceptualisations regarding the applications of rec. DNA technology do not have links with conceptualisations relating to the techniques by which these applications are made possible.

Figure 7 includes the pattern of responses for each student to these items. These data show that qualitative differences in prior knowledge and attitudes exist between the students. It is interesting to note that, even this small number of students who are broadly unified in the absence of any previous formal educational exposure to rec. DNA technology, are in fact heterogeneous in terms of the attitudes and self-reported prior knowledge that they bring to the formal learning situation. For example, student S6 was the most negative in attitude, students S1 was the most neutral.

OUTCOMES OF THE LEARNING TASKS

Aspects of the cognitive outcomes of the teaching session for each student were assessed by reference to the three concepts prepared by each student. A pointer to the prior conceptual knowledge of each

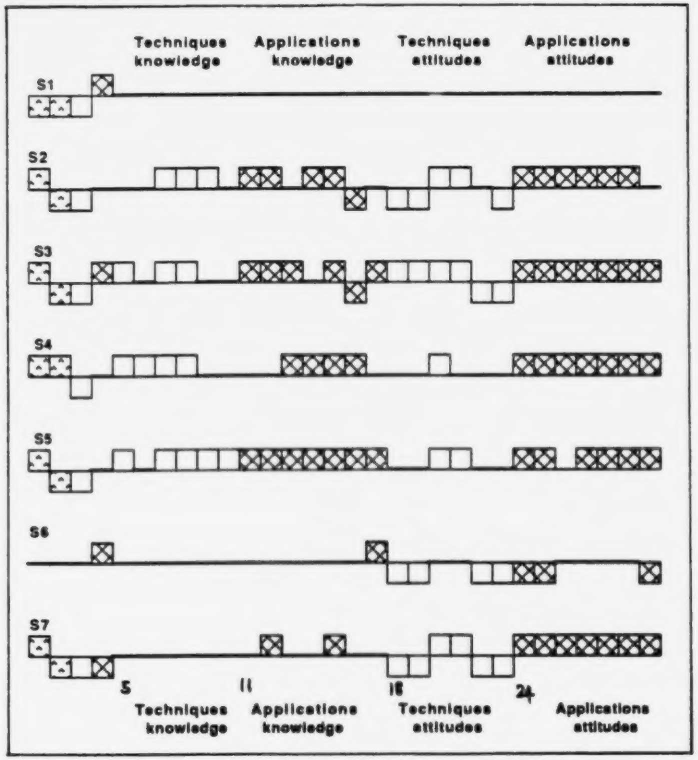

Figure 7: Diagrammatic representation of student responses to items to establish initial or prior knowledge.

Column 1 shows students' responses to item about the common structure of DNA in a variety of organisms. Square ABOVE line: correct; square BELOW line: incorrect; horizontal line: no answer.

Column 2 shows responses to item about the nature of basic unit of DNA. Square ABOVE line: correct; square BELOW: incorrect; horizontal: no answer.

Column 3 indicates general view of complexity of the procedures of rec. DNA technology (ref. Fig.6). Square ABOVE: choice towards simple; square BELOW: choice towards complex; horizontal: midpoint of scale.

Column 4 indicates general view of desirability of use of the technology (ref. Fig. 6). Square ABOVE: choice towards desirable; square BELOW: choice towards undesirable; horizontal: midpoint of scale.

Columns 5 to 30 show responses to items listed in Appendix B. Knowledge of techniques (columns 5- 10) and applications (columns 11-17) shown as follows. Square ABOVE: possible (actual / potential); square BELOW: impossible; horizontal: DON'T KNOW. Attitudes to techniques (columns 18-23) and applications (columns 24-30) shown as follows. Square ABOVE: 'should be done'; square BELOW: 'should not be done; horizontal: 'no opinion'.

student before the teaching session was obtained from the student responses to the prior knowledge tools. For the purposes of this paper, the findings with regard to two students, S3 and S5, are briefly discussed. There were no major differences in the apparent prior knowledge of both students; for example, the definitions of the students (Figure 5) do not suggest any major difference, and both students initially indicated that DNA was made of protein and that DNA was the common genetic material of plants and animals (Figure 7, columns 1 and 2). However, for the tasks involved in the teaching sessions, student S3 may well have had a preference for verbal rather than visual processing (see below) while student S5 may well have been suited by the extensive use of visual graphic images. For example, student S5 reacted positively to the symbolism, and wrote of 'understanding while watching' and of 'wanting to see the program again to clarify it in my own mind'. Student S3 wrote of preferring 'lists of words'.

Appendices C and D show the three concept maps prepared by these two students during and at the conclusion of the teaching sessions. Map1 is the DNA map and maps 2 and 3 are the mid- and late-maps on rec. DNA technology. Both students reported that as a result of the teaching and the use of the program, their understanding of the structure of DNA and of rec. DNA technology had increased.

With regard to map1, student S5 has generated a large number of relevant and valid propositions, and the map indicates that this student had learned about DNA in a meaningful manner as a result of the teaching with the computer program. Similarly, map1 generated by student S3 shows a sound conceptual framework. It is of interest to note that while there are many common elements in map1 of students S3 and S5, there are differences; for example, student S3 has included the concept of **bonds** , and has linked this concept to **base pairs**. Student S5 has omitted the concept of bonds, but has included the proposition that **DNA obeys the same rules.**

For both students, map 3 shows fewer misconceptions and more appropriate linkages than map 2. However, there was a difference in the quality of all three maps of student S5 when compared with those of student S3. In the case of student S3, although map 2 centers on DNA, it is sparse and while some individual propositions are valid, their summation is flimsy. Map 3 of student S3 includes faulty propositions that suggest confusion regarding the action of reverse transcriptase and the link between recognition sequence and plasmid.

In so far as the concept maps provide pointers to the students' conceptual frameworks, the limited teaching session in the case of student S5 appears to have been associated with the establishment of many key concepts and with their inter-connection as a number of appropriate propositions. It is interesting to note that for student S5, map 3 shows a clarification of the role of reverse transcriptase when compared with the corresponding section of map 2. It is also interesting to note that student S5 incorporated graphic symbols into map 3. Given the limited time available in the teaching session, student S5 shows evidence of meaningful learning and has in that time demonstrated evidence of significant restructuring of knowledge.

When compared with the baseline of prior knowledge that was established for each student, the activities within the teaching session appear to be correlated with the initiation of a framework relating to the techniques of rec. DNA technology. This statement does not imply that other activities would not have been equally or more effective.

The comments of all students in the group with regard to the visual images used to signify the 'tools' of rec. DNA technology in the program are summarised below. For the majority of students, their written comments coupled with their concept maps suggest that the graphic images may have acted positively in several ways, such as engaging and interesting the students, assisting them in encoding and retrieving the verbal labels of the enzymic 'tools', and assisting them in linking a function with a verbal label. This is not unexpected, given that many researchers have investigated the role of visual images in facilitating aspects of information processing and cognition; for example, Kosslyn and Pomerantz (1977), Carbonell (1983), Lynn, Shavitt, and Ostrom (1985), , Gilder (1985), Swanson (1987).

Student comments relating to the use of the graphic symbols included the following:

> ". . . reduced the seriousness of the content to something which is a simplified sequence of actions - cutting, joining, trimming."
> "Good symbols, but nuclease was the best symbol of all."
> "Poetic licence. Symbols put the whole into an easily recognizable framework. Metaphor aids instruction."
> "Reminded me of a function. Helped otherwise unfamiliar material which initially is quite complex."
> "Symbols provided some sort of mental picture of each chemical's ability, for example, nuclease to 'eat' away unnecessary element in a helix."

However, one student in the group indicated a clear verbal preference. This student wrote:

> "I would have preferred lists of words and functions which I could read and absorb. I got the words confused and forgot the names."

At a practical level, individual differences in visual and verbal processing are the subject of consumer research (for example, Childers 1985).

In addition to their visual nature, the images for the 'tools' of rec. DNA technology also included an element of metaphor and analogy, and this element is transmitted to the user of the program principally by graphic visual cue rather than verbal label cue.

The use of verbal analogy has been investigated by researchers including Gick and Holyoak (1980, 1983). Driver and Erickson (1983) have suggested that the available metaphor in language may be a source of ideas used to assimilate a new experience into a familiar one. In a review, Vosmadou and Brewer (1987) list metaphors and analogies as mechanisms for radical restructuring of knowledge. It is reasonable to suggest that visual and analogical images facilitate the construction of meaning for learners faced with an abstract and unfamiliar set of new concepts such as rec. DNA technology. However, given the variation in learners that is expressed in various ways, including their prior knowledge (for example, Finlay 1984), their relative visual and verbal information processing skills, their affective states . . . , meaningful understanding of concepts is best addressed by providing learners with a range of cognitive experiences providing input via many sensory modalities.

Because of its social and ethical consequences, the domain of rec. DNA technology or genetic engineering will increasingly be the subject of instruction for students of many disciplines. This study has shown that concepts relating to the technology can be established and developed in learners through use of computer-based activities that include graphic images and analogies. On-going studies will investigate the stability of the conceptual frameworks in the student group, and, in particular, will seek to identify and explore a modality-rich instructional sequence that facilitates a range of learner attributes.

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APPENDIX A

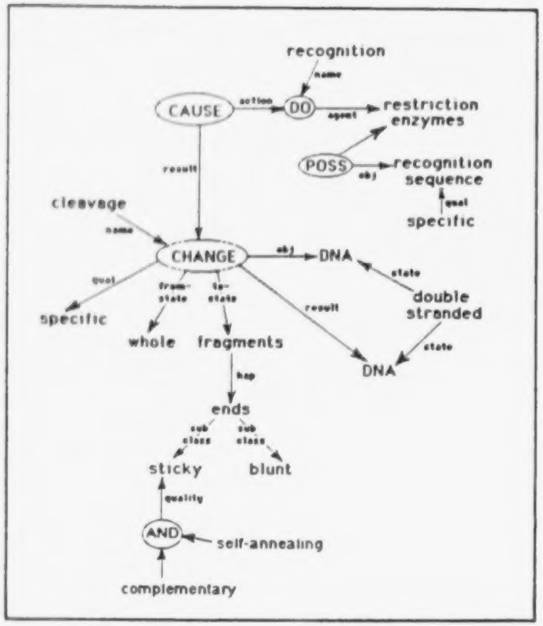

recognition
name
CAUSE
action
DO
agent
restriction enzymes
POSS
obj
recognition sequence
goal
specific
result
cleavage
name
CHANGE
obj
DNA
state
double stranded
qual
specific
from-state
to-state
whole
fragments
result
DNA
state
has
ends
sub class
sub class
sticky
blunt
quality
AND
self-annealing
complementary

Figure A1: Action of restriction enzyme: Active structural network.

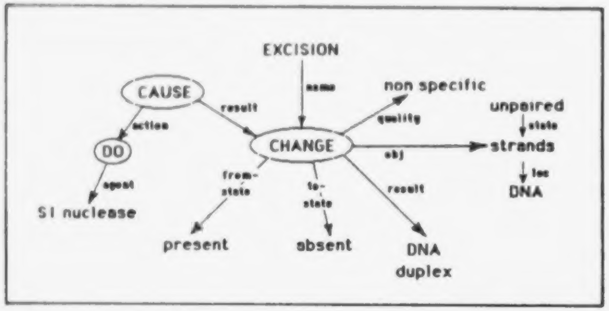

EXCISION
name
CAUSE
result
action
DO
agent
SI nuclease
CHANGE
quality
non specific
unpaired
state
obj
strands
loc
DNA
from-state
present
to-state
absent
result
DNA duplex

Figure A2: Action of nuclease: Active structural network.

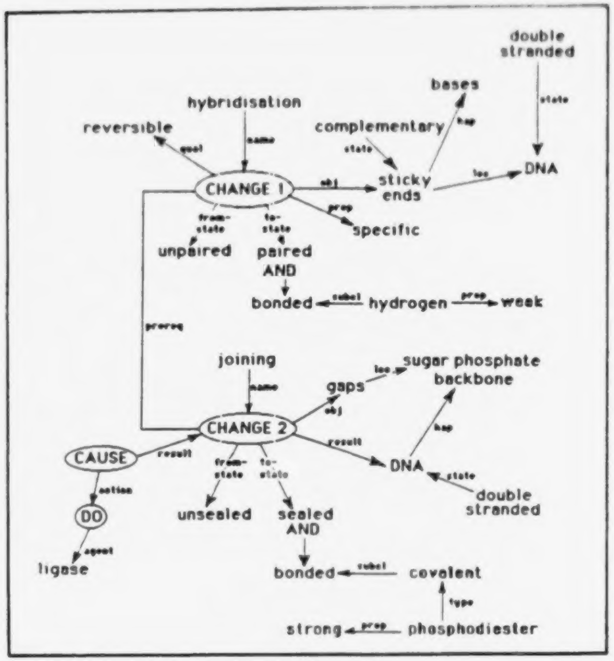

double stranded
bases
hybridisation
reversible
complementary
name
qual
state
hap
loc
CHANGE 1
obj
sticky ends
DNA
prop
specific
from-state
to-state
unpaired
paired AND
bonded
subcl
hydrogen
prop
weak
prereq
joining
name
gaps
loc
sugar phosphate backbone
obj
hap
CHANGE 2
result
CAUSE
result
DNA
state
double stranded
action
from-state
to-state
DO
unsealed
sealed AND
agent
ligase
bonded
subcl
covalent
type
strong
prop
phosphodiester

Figure A3: Action of ligase: Active structural network.

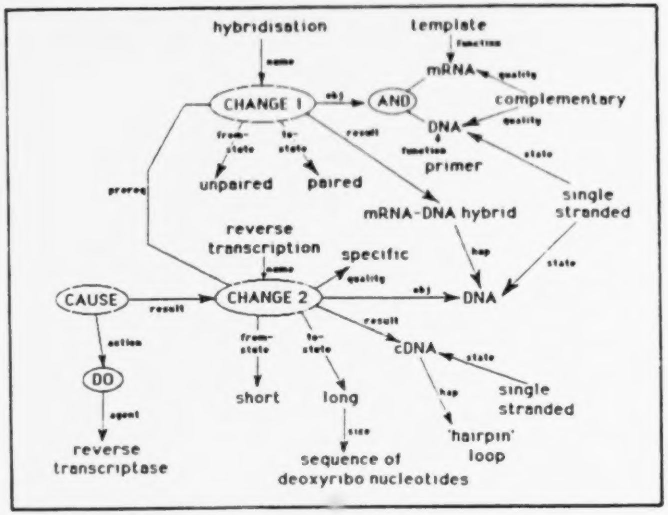

hybridisation
template
function
name
mRNA
quality
CHANGE 1
obj
AND
complementary
DNA
quality
result
function
primer
state
from-state
to-state
unpaired
paired
prereq
mRNA-DNA hybrid
single stranded
reverse transcription
specific
hap
name
quality
state
CAUSE
result
CHANGE 2
obj
DNA
result
action
from-state
to-state
cDNA
state
DO
short
long
hap
single stranded
agent
size
reverse transcriptase
sequence of deoxyribo nucleotides
'hairpin' loop

Figure A5: Action of reverse transcriptase: Active structural network.

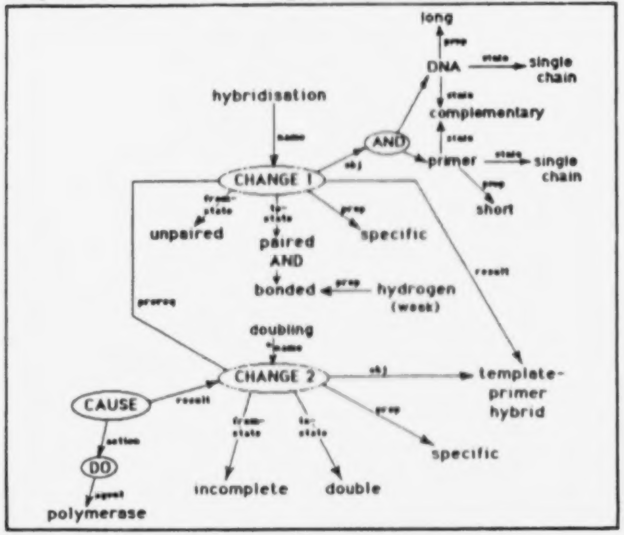

long
prop
DNA
state
single chain
state
hybridisation
complementary
name
state
AND
primer
state
single chain
obj
CHANGE 1
prop
from-state
to-state
short
unpaired
paired AND
specific
prop
result
bonded
prop
hydrogen (weak)
prereq
doubling
name
CHANGE 2
obj
template-primer hybrid
CAUSE
result
prop
from-state
to-state
specific
action
DO
incomplete
double
agent
polymerase

Figure A4: Action of polymerase: Active structural network.

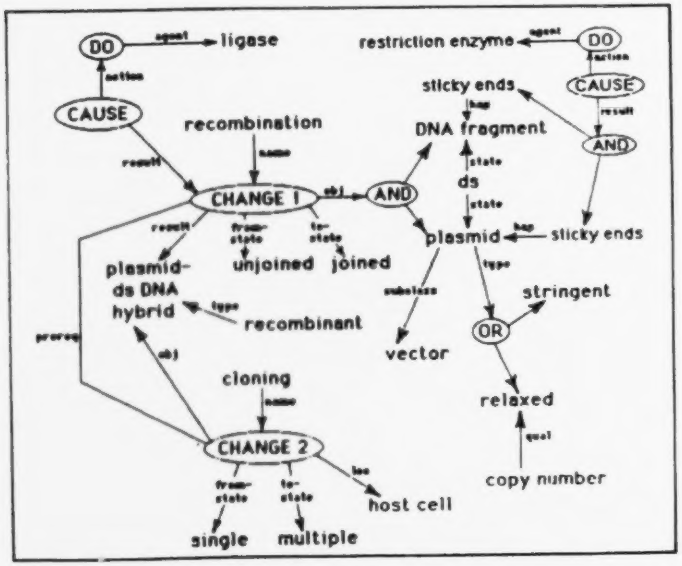

DO
agent
ligase
restriction enzyme
agent
DO
action
action
sticky ends
CAUSE
CAUSE
hap
result
recombination
DNA fragment
name
state
AND
result
ds
CHANGE 1
obj
AND
state
result
from-state
to-state
plasmid
hap
sticky ends
plasmid-ds DNA hybrid
unjoined
joined
type
subclass
stringent
type
recombinant
prereq
vector
OR
obj
cloning
relaxed
name
qual
CHANGE 2
loc
copy number
from-state
to-state
host cell
single
multiple

Figure A6: Formation of plasmid-dsDNA hybrid: Active structural network.

APPENDIX B

Items of techniques and applications of genetic engineering. Students were asked to indicate their perceived knowledge of the feasibility status of each item as either 'possible', 'impossible' or 'don't know'. Students were also asked to indicate their attitude to each item as 'should be done', 'should NOT be done', or 'no opinion'. Students received the items as a mixture of techniques and applications, not as the two distinct lists shown below. The order below corresponds to the order of recording in Figure 7.

TECHNIQUES

T1. Producing many copies of a human gene by multiplying it in bacterial cells.

T2. Using a chemical substance from a virus to assist in making copies of a human gene.

T3. Locating one particular fragment of genetic material from a mixture of many thousands of different fragments.

T4. Cutting out one particular piece from a length of genetic material.

T5. Joining a piece of human genetic material to the genetic material of a mouse.

T6. Making human genes by a process of chemical synthesis.

APPLICATIONS

A1. Using genetic engineering to identify a disease-causing gene in a human fetus.

A2. Using genetic engineering to identify whether or not a young person will be affected by an inherited disease later in life.

A3. Using genetic engineering to make products, such as human growth hormone, for use in medicine.

A4. Using genetic engineering to cure a fatal bone marrow disease by repairing the defective gene.

A5. Using genetic engineering to detect whether a person is a 'carrier' of an inherited disease.

A6. Using genetic engineering to repair a faulty gene in the ovary of a female so that she cannot pass the gene to her children.

A7. Using genetic engineering to prevent frost damage in frost - sensitive plants.

APPENDIX C

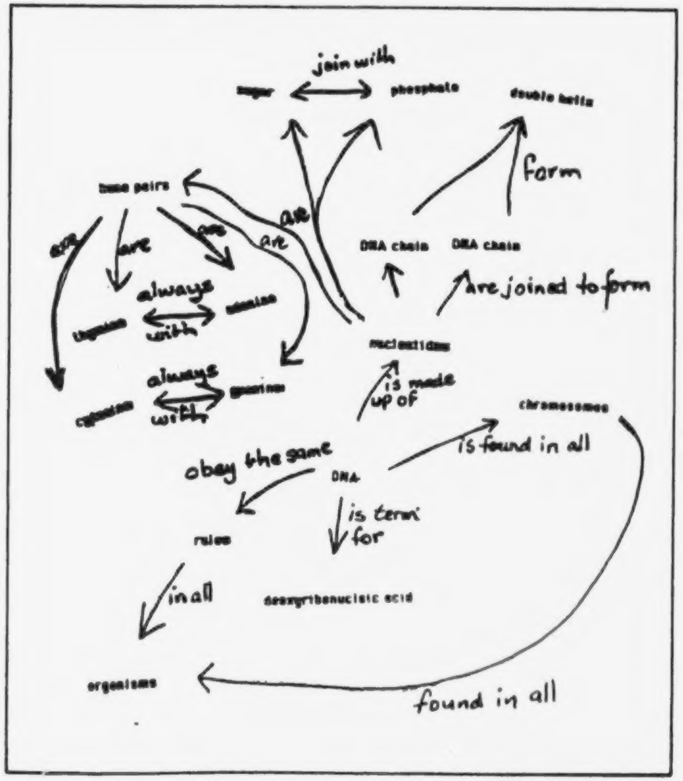

join with
sugar
phosphate
double helix
form
base pairs
are
are
are
are
are
DNA chain
DNA chain
always
with
thymine
adenine
always
with
cytosine
guanine
are joined to form
nucleotides
is made up of
chromosomes
is found in all
obey the same
DNA
is term for
rules
in all
deoxyribonucleic acid
organisms
found in all

Figure C1: Concept map drawn by student S5 after an initial teaching session about DNA. The student was provided with 17 concepts related to DNA and informed that additional ones could be used.

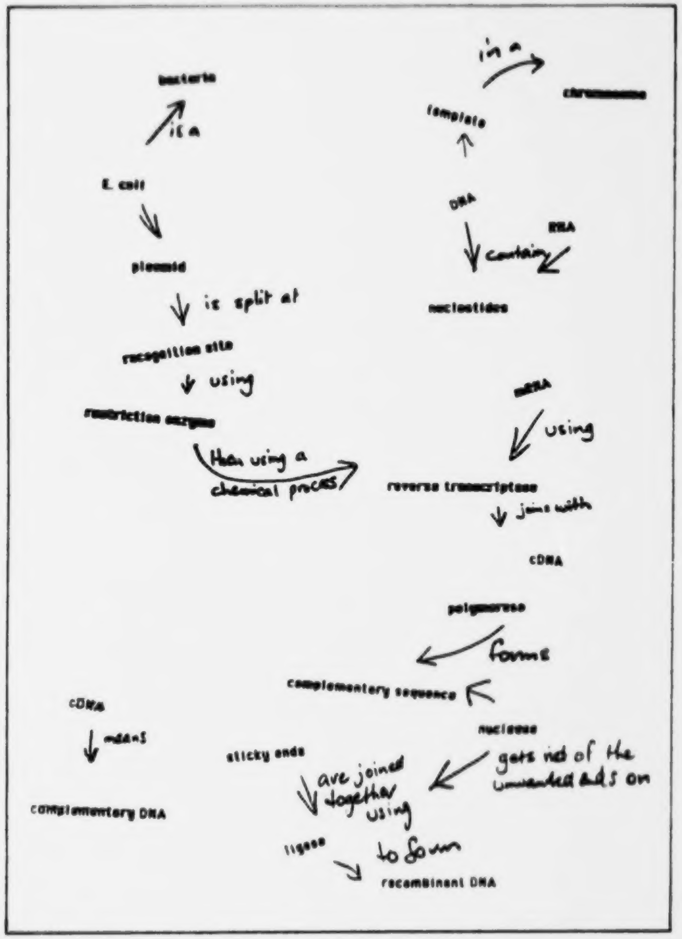

bacteria
is a
E. coli
plasmid
is split at
recognition site
using
restriction enzyme
then using a chemical process
in a
chromosome
template
DNA
RNA
contain
nucleotides
mRNA
using
reverse transcriptase
joins with
cDNA
polymerase
forms
complementary sequence
cDNA
means
complementary DNA
sticky ends
are joined together using
nuclease
gets rid of the unwanted ends on
ligase
to form
recombinant DNA

Figure C2: Concept map drawn by student S5 after an initial teaching session about genetic engineering. Twenty four concepts were provided; students were able to use additional concepts.

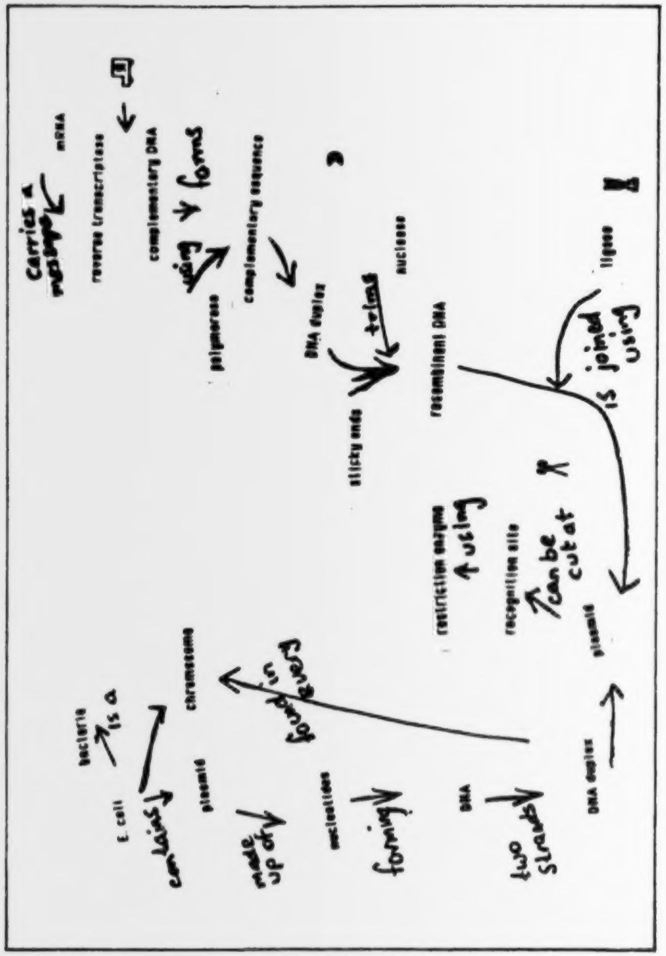

mRNA
carries a message
reverse transcriptase
complementary DNA
using
forms
polymerase
complementary sequence
DNA duplex
forms
nuclease
sticky ends
recombinant DNA
ligase
is joined using
restriction enzyme
using
recognition site
can be cut at
plasmid
chromosome
found in
bacteria
is a
E. coli
contains
plasmid
made up of
nucleotides
forming
DNA
two strands
DNA duplex

Figure C3: Concept map relating to genetic engineering drawn by student S5 after an additional teaching session in which computer simulation was used. The same list of concepts as in C2 was provided. Students were also given copies of the symbols used in the microcomputer program.

APPENDIX D

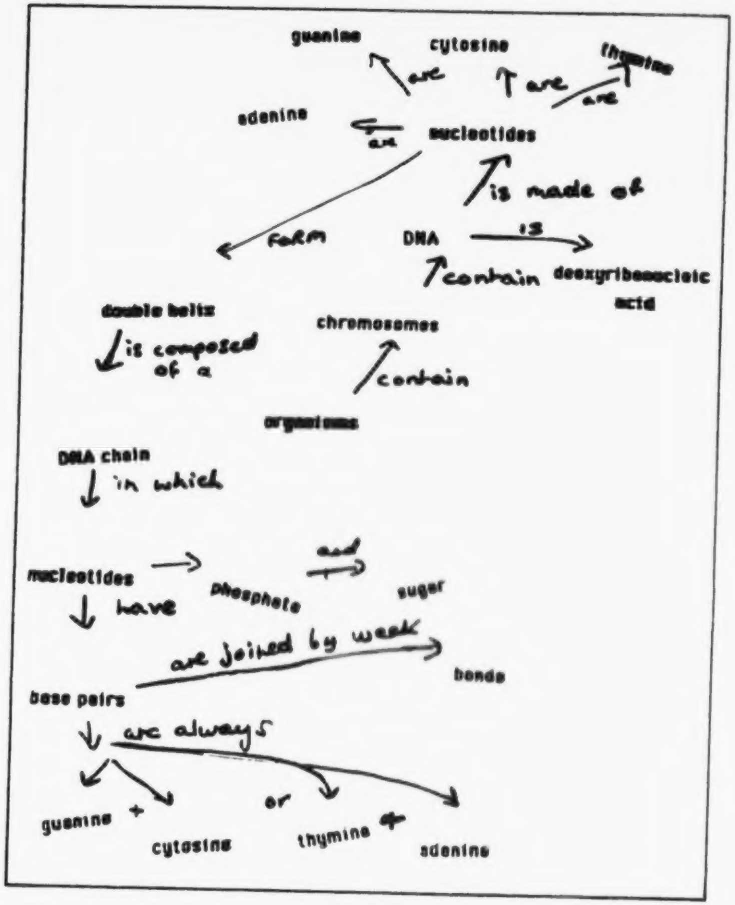

guanine
cytosine
thymine
are
are
are
adenine
are
nucleotides
is made of
form
DNA
is
contain
deoxyribonucleic acid
double helix
is composed of a
chromosomes
contain
organisms
DNA chain
in which
nucleotides
phosphate
and
sugar
have
are joined by weak
bonds
base pairs
are always
guanine
+
cytosine
or
thymine
&
adenine

Figure D1: Concept map drawn by student S3 after an initial teaching session about DNA. The student was provided with 17 concepts related to DNA and informed that additional ones could be used.

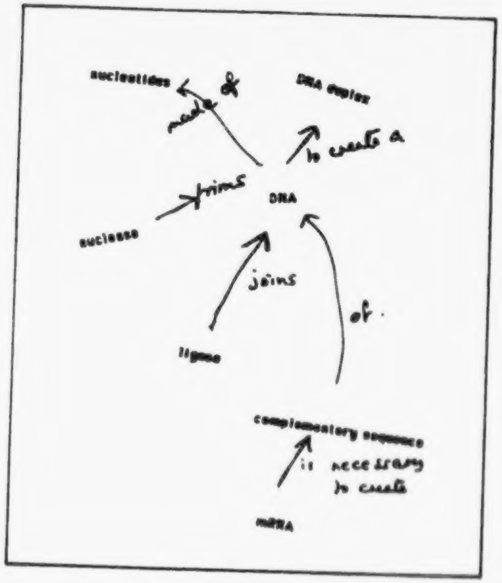

nucleotides
needs
&
DNA duplex
to create a
trims
DNA
nuclease
joins
of
ligase
complementary sequence
is necessary to create
mRNA

Figure D2: Concept map drawn by student S3 after an initial teaching session about genetic engineering. Twenty four concepts were provided; students were able to use additional concepts.

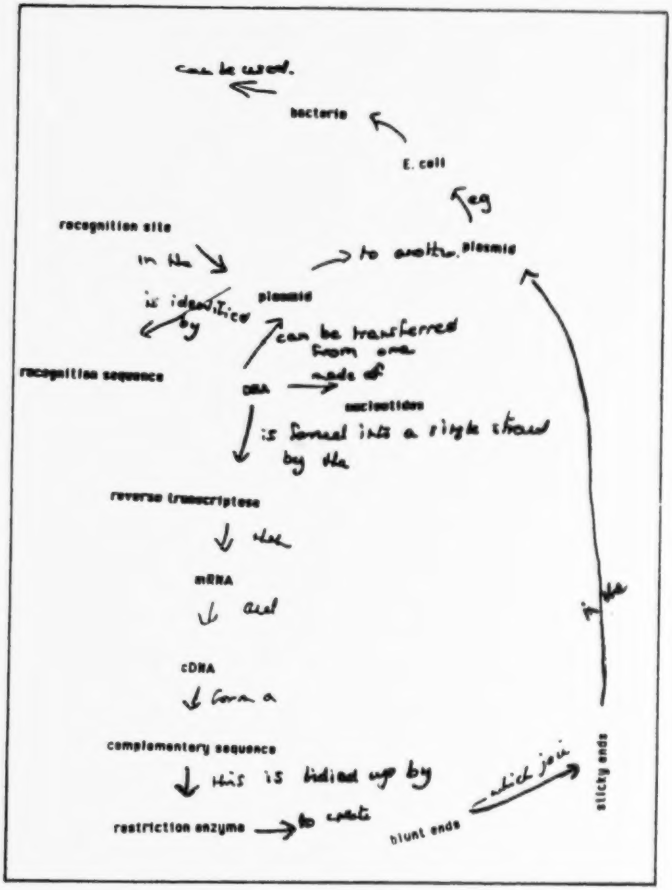

can be used.
bacteria
E. coli
eg
recognition site
in the
to another
plasmid
is identified by
plasmid
can be transferred from one
recognition sequence
DNA
made of
nucleotides
is formed into a single strand by the
reverse transcriptase
the
mRNA
and
cDNA
form a
complementary sequence
this is tidied up by
restriction enzyme
to create
blunt ends
which join
sticky ends
to the

Figure D3: Concept map relating to genetic engineering drawn by student S3 after an additional teaching session in which computer simulation was used. The same list of concepts as in D2 was provided. Students were also given copies of the symbols used in the microcomputer program.

Finding Out What Kids Know or "Straight From the Horse's Mouth"

Christine Kuehn and Danny L. McKenzie, University of South Carolina

During typical classroom discussions or question-answer periods, children have little opportunity to elaborate on their answers. The assumptions made by the textbook authors in regard to the "average" students level of understanding may often be accepted by the teacher without regard to the variety within the classroom. Through the use of individual interviews, teachers have the opportunities to explore their own students' understanding of science concepts. This may allow for the identification of more appropriate teaching strategies or perhaps, more importantly, the teachers' focus shifts from the concept to conceptual changes within the students. As interviewer, the teacher does not evaluate the child's responses in terms of correctness or compatibility with an acceptable scientific concept. Rather, the teacher attempts to establish what the childs' ideas are, however unscientific the idea may seem.

Purpose

The purpose of this paper is to present ideas shared by teachers who have used the interview process with their students. Using the teacher's perceptions, implications for the teaching of science will be presented.

Data Sources and Methods

A total of sixty-five elementary teachers participated in this project. The teachers conducted interviews with their students on two of the following topics: shadows, weather, living and non-living, or day and night. During the interview the teachers followed a suggested set of questions that were developed specifically for the interview process. The questions were designed to elicit the child's perceptions without leading the child toward a predetermined explanation for the concepts. For example, in the interview on shadows the interviewer might ask, "Can you make a shadow appear where you want it to?" After the child responds "Yes" or "No", the interviewer simply asks "Why?" or "Why not?" This style of questioning better elicits the child conception then using a leading question such as, "What would happen if you moved the light source?" The interview process as used in this study was not intended to be instructional but rather to ascertain a child's own understanding. Guidelines for conducting the shadows, and living and nonliving interviews are included as Figure 1.

After completing the interview each teacher summarized each students' response and reactions to the interview process. Also the teachers provided observations and insights concerning the value of the interview experience. From these observations and insights a set of advantages for using the interview process was developed. A set of implications for science teaching also resulted from the ideas shared by the teacher.

Results

Following is a list of the ten most frequently identified advantages and implications of the interview process.

1. **Importance of activities and process oriented science**

   It was noted by many teachers that when students had explored the concept through an activity-based lesson, their explanations of the concept were better formulated than those concepts addressed in an abstract fashion.

2. **Interview as a diagnostic tool**

   Many teachers reported the interviews as being an effective means of assessing students' knowledge of a concept prior to instruction, determining what students know and don't know, and identifying students misconceptions.

3. **Encouragement of thinking**

   The questions in the interviews encouraged high level thinking and the students had the opportunity to answer using more complex and elaborate responses.

4. **Effective questioning**

   The importance of effective questioning became apparent. Teachers pointed out that they valued the use of appropriate questions to stimulate higher level thinking and creative responses. The importance of using appropriate wait-time also became apparent.

5. **Awareness of Variation**

   Teachers reported an increased awareness of the variety of children's conceptions, abilities, and the importance of science in the elementary curriculum.

6. **Promoting Communication**

   The use of interviews was an opportunity to promote oral expression.

7. **Focusing on conceptual change**

   As a result of the interviewing process, teachers recognized the importance of focusing on conceptual change in children rather than focusing on the concept itself. Many children appeared to have partial or incomplete conceptions, and teachers indicated that these concepts should not be considered "wrong" but appropriate as children progress in their understanding of the intended concept.

8. **Interview as an instructional technique**

   Because of the perceived value of the interview many teachers reported their intention to make use of the interview as a pre-assessment to aid in designing appropriate instruction.

9. **Attitudinal advantages**

   The interview situation appeared to foster self-confidence in many of the students. Teachers suggested this might influence students' attitudes toward science.

10. **Concerns for "correctness"**

    Even though each teacher had assured each student at the beginning of the interview that there were no right or wrong answers, that the teacher was interested in hearing the students' ideas, some teachers reported that students from "structured classes" were still concerned about correctness of responses.

In addition to the aforementioned most frequently cited advantages and implications, other insights made by a few teachers are perhaps also noteworthy. Several teachers noticed a similiarity of their students' level of understanding of a concept and the progression of intellectual development as described by Piaget and others. Some other teachers suggested a relationship between relevant science experiences in settings other than the classroom, such as, museums, zoos, and natural settings and children's responses during the interviews.

Conclusion

This study focused on teachers using a unique method of finding out what their students know. Although none of the teachers had used the interviewing process previous to this experience, it is evident through their insights that those experiences were enlightingly and valuable. Most of the teachers have indicated a continued use of the interview process in their classrooms.

A CASE STUDY - ON THE 'JOURNAL METHOD'- A METHOD DESIGNED TO ENABLE THE IMPLEMENTATION OF CONSTRUCTIVIST TEACHING IN THE CLASSROOM

Kenneth Kuhn (Argyle School North Vancouver District)
with the collaboration of
Dr. Jose Aguirre (University of British Columbia)

This paper consists of six sections:

Section one is introductory. It focuses on a case study of an attempt to implement constructivist teaching with a grade 10 science class.

Section two describes a "Journal Method" designed to facilitate the use of constructivist teaching methods in the Classroom.

Section three contains student comments made at the end of the implementation period regarding the "Journal Method".

Section four has a discussion of a proposed teaching model generated after an analysis of the case study as it relates to the "Journal Method".

Section five gives the characteristics of and conditions for interpretive-constructive teaching that were identified in the case study.

Section six delineates conclusions that may be drawn about the "Journal Method" as a process facilitating classroom learning and understanding.

SECTION ONE AN INTRODUCTION-

This case study took place in the second year and second phase of an ongoing research project called: "the Development of an Instructional Approach based upon a Cognitive Perspective". It involves personnel from the Department of Mathematics and Science Education at the University of British Columbia as well as three science teachers working in the public school system. The second year involved the implementation and field-testing of materials in regular classroom settings under normal teaching conditions.In particular a "Journal Method" was developed for this case study. The intent was to modify and improve this method while it was being implemented. This process can be conceptualized in terms of Schon's (1983) notion of "reflective practice". He claims that:

> ...We are in need of inquiry into the epistemology of practice. What is the kind of knowing in which competent practitioners engage? How is professional knowing like and unlike the kinds of knowledge presented in academic textbooks, scientific papers, and learned journals?
>
> (Schon, 1983, p.viii)

The case study discussed here was undertaken during the third month of the school year (1986-87) and involved the second unit (radiation and nuclear energy) of the grade 10 science curriculum for B.C.. The two main members of the team for this case study were Ken Kuhn (school teacher) and Dr. Jose Aguirre (University personnel and observer). They used an action research approach in assessing the daily one hour classes. In addition a student teacher was periodically involved as an observer and at one point in an instruction role.

Three main objectives were defined for the study:

Objective one- Six generic teaching strategies, that is strategies that can be used in different contexts and for different topics, would be used in a constructivist mode. These six are brainstorming, cartooning, debating, drawing, media (films, videos), and model building (including simulation games).

Objective two- The team would attempt to identify micro-teaching episodes in which students were using their conceptions as explanations of a phenomena being discussed and the teacher is forced to use those conceptions in coming up with a micro-teaching strategy to deal with the situation in a constructivist manner.

Objective three- An assessment of the "Journal Method" would be made in terms of its ability to facilitate the implementation of an interpretive-constructivist mode of instruction. Student reactions during and after the study were to be identified. While dealing with these objectives the team was attempting to distinguish between interpretive and transmissive modes of instruction.

The class consisted of 14 girls and 18 boys. This class of 32 students met in a science laboratory which was arranged to decentralize the teacher's desk and teaching location. There were several 'paths' in the room designed to enable the teacher to move quickly around it.

Although it took 20 one hour lessons (this corresponded exactly with the time allotted for the unit in the prescribed curriculum) to go over the unit it was divided into six topics or themes. These were the following:

1. The electromagnetic spectrum.
2. Types of nuclear radiation.
3. Isotopes and rules for nuclear reactions.
4. Time and radioactive decay.
5. The biological effect of radiation.
6. Using nuclear energy.

A number of lessons were planned for each topic. Although each topic was developed in a similar sequence, different strategies were used in many cases. Flexibility was deliberately injected. Provision was made to either reduce or extend the allotted time if needed. Also, lessons were adapted to the emerging requirements of the unit as it progressed. During this period the teacher kept his own journal containing his own reflections on the process, the planning involved, and particular student responses which occurred during the lessons.

Eight students were randomly selected from the class of 32 and were asked if they wanted to participate in interviews in order to identify the 'insights' of the students' about the science instruction after the unit was completed. All of these agreed to participate. Other students were asked to answer a questionnaire composed of questions similar to the ones in the interview protocol.

SECTION TWO - A DESCRIPTION OF THE "JOURNAL METHOD" WITH STUDENT EXAMPLES-

The "Journal Method" was developed by the teacher. It was the product of his teaching experience and the discussions carried out in the project team during the first, or development year. He had concluded that the traditional laboratory report did not fit well with the new constructivist mode. A journal or a sort of comprehensive report including all of the activities such as lab work, demonstrative experiments, films, discussions, readings, homework, and conclusions for each topic should be written by students. It usually took several lessons, to complete such a journal report and students worked on it in class and at home. At the end of the topic, journals were handed in to be marked by the teacher.

The six journal reports had a similar format and a covering sheet was provided for each. At the beginning of each topic a "prequestions" section was used to record student conceptions prior to instruction regarding two or three major question in each topic area. This is followed by an activity section. Students are given several problems and a brief description of each related task. They are to complete these tasks and describe "what happened" in each case as a part of their journal write-up. In other cases media or any other mode of presentation is to be described using student language in the same way. A "debriefing" section follows which involves an interpretive discussion led by the teacher. After including any other assignments taken from a variety of sources each student had to conclude their report by identifying what they had known before the activity, a few main points that they had learned and one or two questions that had been stimulated by the activities in the theme and had not been or perhaps could not be answered.

The following format was used for student journals:

1. NAME-
2. DATE-
3. TOPIC-
4. PREQUESTIONS-
   (state these as given by your teacher: feel free to add any additional ones.)
5. PRECONCEPTIONS-
   (answer the prequestions from your own experience. Don't worry about "right" answers.)
6. WHAT HAPPENED-
   (describe your observations briefly)
7. PERSONAL NOTES-
   (Make any notes for yourself here which come out of the debriefing discussion)
8. ASSESSMENT-
   A. What were some things that you already knew about what you observed?
   B. What result(s) if any surprised you?
   C. State some questions that you have which are about what you observed or are related to it.

   D.State any everyday examples or applications of what you observed.
9. YOUR CONCLUSIONS-
   (Briefly summarize the main points covered in this journal report.)

In the following segment of the paper selected student responses taken from the six journal assignments described above will be used to illustrate the generic teaching strategies referred to and the "Journal Method" described as well as some examples of micro-teaching strategies.

Journal Entry one- The electromagnetic spectrum

Brainstorming was used prior to instruction to determine associations made by students with the word "radiation". They were given the following tasks:

> Make a list which is as long as possible of words that sound like radiation. You have a four minute time limit. Then combine your lists with those of four other people and put them on the blackboard. Have your group classify the words on the board by meaning and decide how each illustrates what radiation is.

Many items on the list such as ray or radio had the sense of a source, a transmission of energy and a detection. Many others had intriguing explanations accompanying them. For example:

> Radical- is like radiation because radiation comes from a source like a root comes from a plant.
>
> Exfoliation- when a rock is lifted from deep in the earth's crust, it radiates pressure and cracks the rock and forms sheets that peel off like an egg shell.

The following student responses to the prequestion, "What is radiation?" illustrate the function of such a question in the format of the journal report:

-radiation means to transmit signals such as radio waves, solar waves through air or fluid.

-radiation means that an object has an invisible field around it; it may also be visible.

-radiation means the invisible wave we feel after a nuclear explosion.

Six stations were set up to illustrate radio-waves, the visible spectrum, ultra-violet and infrared rays. For example one station had a simple radio receiver with earphones and a dry cell with a small resistor to set up a simple radio transmitter. Radio waves could be generated by mechanically opening and closing the circuit. Such factors as range and code transmission could be tested. Another station used soap bubbles and a white light source to show the visible spectrum while another used a vinyl record to do so by diffraction. Some student comments were the following:

-static in radios is caused by bad frequency.

-different radio waves interact with each other causing static.

-looking through a bubble (soap and water) causes diffusion into the spectrum.

-spectrum of white light is produced by the metal on which the light is reflected.

One assignment that was given required the students to find out what color temperature was. Interestingly, a number of students concluded that red hot was a higher temperature than blue hot . This seemed to coincide with our cultural representation of temperature. Fire engines, warning signs and stoves are red. Water and sometimes cold water taps are blue. In the debriefing some students remembered being told (incorrectly) in a previous science class that red stars were hotter than blue stars. They were reluctant to relinquish this conclusion given to them by an authority previously encountered in another science class. One part of the discussion is given next and illustrates the use of one student debating another when the 'right' answer is not clear.

Teacher..Stars have all kinds of different colors ...Stan, help me with this. If you look through a telescope it is quite easy to find a star that is blue. They are usually quite young stars, and there is another kind. There is one called a red giant. Which one of those is a higher temperature?

Stan.. The red one.

Teacher..Why the red?

Stan and others..Because it is red. It is hotter..And has lived more.

Teacher..It happens that they have different life spans, but that doesn't matter necessarily. Ah, Tammy, you disagree with Stan. Why do you think the blue star is a higher temperature?

Tammy..The blue star is bleaching out and it is kind of lighter. The flame is going up. The flame is blue like a Bunsen Burner. You can't control the gas there.

Teacher..Then you think Stan is wrong. Why do you think so?

Tammy..I just think he is.

Student journals for this section had these kinds of questions at the end:

-Are there always some sort of non-visible light around you? (Are there always gamma, cosmic, and radio waves around?)

-Is there any material that the non-visible light rays can pass through?

As well, the following kind of everyday example would be included at the end of many journals.

-When you drive into an underground parking lot your radio always goes out or really dim because its radio waves aren't going through.

Journal entry two-Types of nuclear radiation

This second entry will be used to illustrate an additional example of a micro-teaching strategy as well as the use of verbal analogies.

Perhaps the most clear exemplar of an interpretive micro-teaching episode occurred when a student notice the "unevenness" of interval clicks on a Geiger Counter as it was being used with the class as a whole to measure background radiation coming from the environment. The teacher on the spot reflected on the event and created a micro-teaching strategy which took into account the student's conceptions. Within this strategy he asked the student to explain and expand her observation; next he involved the whole class in the discussion, and created a number of steps to smoothly introduce the concept of randomness in radioactivity.

Susan..And the clicks (heard through the speaker) happen at uneven intervals. Is that supposed to happen? Teacher ..Well, what do you think? Has anyone else notice what Susan has heard?

(several students agreed by nodding)

Stan..Yeah..Clicks happen at random.

Teacher..What do you mean by random?

Stan..Well, you can't predict when it is going to happen precisely..And happens at random?

Carol..playing with dice. When you roll a dice...You can't predict what number will be!

Teacher..Yes. If it happens at random or by chance, mathematically it's called probability, it tells you that something is not regular like other things. Now I would like to measure background radiation and I'm not sure how to do it. Dave, what sort of measurement, will we use?

No response

Teacher..How am I going to assign a number to tell the background radiation?

Gary..Just count.

Teacher..If we do it we can get 1000..What does it mean?

No response

Teacher..What else do we have to measure?

Stu..Measure how many per second or per minute.

Teacher..And then get the average?

Stu..Yeah.

Teacher..Well let's do that. Okay, how long should we use?

Students..One minute!

Teacher..Let's try that. Craig, tell me when to start and how many in one minute.

Craig..9 (most of the students agree on 9).

Teacher..If we take the measurement again, what is your prediction?

Students..9..8...10..11..9.

Teacher..Ann will time this time. Tell me when to start and what is the count?

Ann..It's 11 this time.

Teacher..Let's do it again. Are you ready Anita?

Anita..Now it's 12.

Teacher..If we do it again, can we get 12

The majority of the students said no!

As a final assignment students were required to formulate analogies by answering the question: How is nuclear radiation like a hunter, a pair of dice, a friend? Some of the responses which indicate student thinking were:

A. Radiation is like a hunter because-

-It can shoot out and kill or destroy things.

-it shoots out parts of its nucleus like a hunter shooting a gun.

-the closer it comes the more dangerous it gets.

B. Radiation is like a pair of dice because-
-they always give random results like radiation does.
-it is very unpredictable.
-if you use it wrong or don't use it properly you can be gambling with your life like a game.
C. Radiation is like a friend because-
-Once you are contaminated it stays with you like a good friend.
-you have to treat it carefully or else it can be dangerous to you.
-it can be very helpful to certain things like a friend.

Journal entry three- Isotopes and rules for nuclear reactions.

In this section model building as performed through a simulation game was implemented as a generic strategy. Also one lesson was taught by a student teacher who had been observing the methods used. Finally the issue of pacing and rate adjustment as it relates to constructivist teaching arose.

In the simulation game the idea was to represent the structure of the alpha particle and isotopes of hydrogen or helium with students playing the parts of individual protons, electrons and neutrons. Students taking acting class were selected as leaders of their teams. Each of the students was labelled and each team presented its particle as a skit with the rest of the class having to identify the unknown particle. Each presentation was photographed with a Polaroid camera and these were immediately displayed. These structures were then reviewed and elaborated.

The lesson taught by the student teacher was centered around the use of isotopes to determine the properties of glacial ice and snow, a project that he had worked on and had a set of sides which he had taken at that time which he was able to use in his lesson. The most striking aspect of this lesson was related to the students' behaviour. There was almost no difference between their behaviour in this period and any other period. This may mean that students had acquired the habit of becoming involved in this type of discourse with any instructor prepared to do it.

Prior to one of the lessons the teacher had a 'hunch' that some students still had difficulty with nuclear reactions or decay equations and as a result he planned to spend much of the period reviewing this topic and give more problems as assignments. The observer noticed that the teaching pace is usually set according to the students grasp of the topic and the teacher was constantly monitoring this. If the majority of students showed signs of having difficulty grasping the concepts, he would slow down, rediscuss the critical aspects of the concepts, and would provide more examples and exercises.

Journal entry four - time and radioactive decay

In this section a different kind of simulation game was used to illustrate radioactive decay over time. Its main feature was that the simulation was conducted by a student who made a point of asking permission to do so. In addition a scientific dating puzzle was given before instruction as an introduction to the method of carbon 14 dating .

In the simulation exercise pennies were distributed to members of the class. These were tossed and a head was deemed to represent the decay of an atom with each penny standing for a radioactive atom. At each toss the "decaying" pennies were collected and placed in separate beakers, one beaker for each toss number. When the beakers themselves were lined up they resembled a bar graph. The data collected was graphed and compared to a statistically predicted graph line. It happened that the activity was interrupted and had to be completed the next day. It was at that time that one of the students earnestly requested that she be allowed to conduct the next lesson which repeated the exercise from the beginning. She was able to do so very successfully and received the cooperation of her classmates. Again this was taken as evidence that the students felt in charge of their own learning.

A collection of items consisting of driftwood, peat, coal, and fossils was presented to the students. Their task was to sequence these in terms of their relative age. They had to call on previous experience to do this. A striking feature of the responses was that, although their solutions varied considerably the students no longer feared error. They simply tried their best. An interpretive discussion followed which exploited the students conceptions as proposed in their solutions to the puzzle.

Journal entry five- the biological effects of radiation

This section used cartooning, a new strategy, to elicit the emotional component of the problem. Students were required to sketch a cartoon about the effects of excessive radiation on people. The most striking feature of the cartoons was that of clearly showing the emotional aspect. Besides including the known side effects of radiation such as loss of hair, lack of appetite, etc, some cartoons showed unhappy faces, open wounds, and short phrases such as: why me? It's terrible! Cartoons proved to be a valuable tool to elicit students' intuitions and feelings.

Another new strategy was implemented unintentionally. It may be called "meaningful reading". Students were asked to carefully read assigned pages but when answering the questions they should use their own words to rephrase and explain what the book was saying, to show that they

understood the concept. They were told that an answer that was a straight copy from the textbook would show a poor understanding of the concept.

Some of the most interesting student responses in this journal assignment were those that tried to distinguish between radiation intensity (RI) and radiation dosage (RD). Some examples are:

-RI is the amount of harmful radiation in the air and RD is how much goes through your body.

-RI is the amount of concentrated strength the radiator has and RD is how much radiation there is on you or being exposed to.

-RI is how hot or strong the rays are: RD is how much (quantity) radiation a person can handle in her/ his body.

A good example illustrating the further questions section of the journal generated by a student in this section is:

> "Why does some radiation cause effects right away, and other after a long time?"

Journal entry six- using nuclear energy

In this section two more teaching strategies were used. These were the debate and student drawings.

Two debates were conducted. One dealt with the question of the desirability of building nuclear reactors and the other with the proliferation of nuclear weapons. The salient features of the debates in the context of the case study were: that the participants had to argue in support of positions that they did not necessarily believe in and that after the debate other students would vote on which team presented its arguments best as well as which position they were convinced to believe in by the debate.

Student drawings of nuclear reactors were used as a strategy at this point to identify their conceptions prior to instruction. This strategy had been used very successfully in a previous unit in which they had drawn their conception of atoms. It had been determined from that previous task that it was useful to try naming as many parts as possible. This was done for the reactor and the drawings were to include any parts that they had heard about. Most of the drawings contained external features only and were sinister in appearance. As a final dimension to this activity the students were required to compare their sketches with a diagram contained in their text books. Their task was to state the similarities and differences between the two.

SECTION THREE - STUDENT COMMENTS FROM INTERVIEWS

The responses of the eight randomly chosen students in the interviews and of the remaining students to the questionnaire indicate that the 'way' (an interpretive-constructive mode of instruction) was carried out was different and more interesting than 'traditional ways' (transmissive instruction); more learning occurred and made the schooling task more comfortable.

Next a selection of responses to the interview protocol are given.

1. How do you feel in science class?

-Well, I like it...I like the way he teaches, because he asks us a lot of questions, and, well, it is kind of hard too...He asks us first what we think, and then you can kind of compare your answer to the real thing ...Well, on some topics I guess you can't really have a right answer,(Do you think he is really considering your ideas when he is teaching?) He looks like he is interested in it and takes it seriously.

-I like the way the lab works, because...He asks you to ask questions about the lab. I think that is kind of neat, because in some classes before, you do a lab and they don't really read it over...What you really think of things.

--I used to hate science. I hated going to science, I hated everything about it. But now I can really get into it, and understand everything that he is saying, because of his experiments.

2. Does it go slow? Fast?

-No, it's not slow or anything, it's just when he teaches it, you can understand everything. Like, he'll go over it in different examples, in ways that you can understand it.

3. Is there much pressure on you now?

-I don't feel there is too much pressure on me.

- Yes, because you have to get all the information for the lab in, because everything you do is part of the lab.

4. Have you noticed anything special in Science 10?

-Yeah...In the journal you can write what you like.

-Well, it is not right out of the book. In every class that I had before, they took it right out of the book, did everything out of the book and it got kind of boring..But I like it this way better.

-He's not higher up and looking down at us like we are just students.

5. Do you find any difference between science classes and other classes or with Grade 9 science?

-I think this is better, because in the years before, we used textbooks, and you did the labs right out of the textbook. If you do your experiment wrong or you don't understand it, all you do is turn ahead to find out what was supposed to happen or what you are supposed to have learned.In this one you don't have much idea, and you sort of figure it out for yourself. By the time he gets around to the debriefing, you end up with a pretty good idea.

6. What do you like in science classes?

-I think I like the debriefing best...Because by the time you get around to it you already know most of everything and he gets your ideas to write things down, gets things from the whole class.

-I used to not like science class at all, but now this is my favorite class. I come here and have a lot of fun and I learn a lot.

7. What don't you like in science classes?

-Well at first I didn't like it because it was totally new. But now I like it a lot.

-I don't think there is anything that I don't like.

8. Can you do the experiments with the minimum information that is give to you?

-Yes, because afterwards he explains it, in the debriefing. But if you go around to the stations and you draw the picture...And say like you think it is right, it doesn't get you any marks off, because you just are saying what you think.

-Yes, I think it is more fun because you get to try to think of the rest of the answers yourself.

9. What do you think about writing journals?

-There is something special about each lab.

-I feel as though I can't do a perfect journal because I'm not used to doing them. But I am finding it easier, because when you go to study, it is there. If you missed something in a lab its gone, but in the journal, like we've got your answers compared to other students. We talk about them and you write down your thoughts.

10. Do you feel it is a good idea to provide your own ideas in the journal even if sometimes your idea is not complete, or even wrong?

-Yes..Because you've got to look back and see what mistakes you did make..When I'm studying for tests, I just read over the labs and look back and see what I thought about it.

-I don't worry about being wrong; it doesn't bother me. It never has!

-Most of the ones we are doing right now I didn't know a thing about, but I guess I like it because you can compare, like you know that you have learned something because you can check back to see what you thought about it before..It doesn't matter if it's right or wrong. He is just trying to find out what you think.

11. Do you think you learn more with this method?

-Yes, because you are not memorizing, you are figuring things out.

12 Do you work harder with this method?

-I don't know whether I'm working harder but the time I'm putting into it is a lot more productive..The other way (lab report) you spent more time worrying about how your lab report looked instead of what actually was in it.

-Maybe...But you don't really notice it.

-Way harder!

13. If you think you are learning more, is it because of the teacher's personality or the way he teaches?

-the teacher sort of sets the mood.

-I guess it's a mixture of both ..He goes over things.

14. Are you more interested in learning science now? Why?

-I'm interested even when sometimes I don't really understand.

-I am more interested now...I'm not sure why.

15. Do you think that science already has all the

explanations to understand how nature works or are there still things to know?

-Oh, there is lots more to know...We will be able to know more, but I don't think we will ever be able to know everything.

16. Do you think that scientific ideas already accepted may change in the future?

-There is a good chance, because it has occurred in the past.

-I guess it could...But I think they will be more or less the same in my lifetime.

The responses in the Questionnaire, written by the students which were not interviewed were similar to the verbal ones expressed by the eight students interviewed. Only one student out of the 24 wrote "feeling not comfortable in science class". Four of the 24 students said there was no difference. The remainder wrote: atmosphere is better, intermixing labs and discussions is good, the lab write-up technique is much better because we can write down our own opinions, in other classes teachers are always watching, it's different but I can't tell what, students participation, more comfortable, learning more, it goes smooth, etc.

SECTION FOUR- A PROPOSED TEACHING MODEL

After the case study was completed a number of discussions occurred in which an attempt was made to describe what was occurring in the "Journal Method" from a theoretical point of view. Two perspectives emerged in the teacher's perception of the learner and of the learning process involved.

The first component had to do with the cognitive structure of the learner. At any moment a large variety of components exist within the learner's conscious and unconscious mind. Some of these that interact in learning situations are:

-formal principles of science already learned or memorized which provide language for conceptions.
-a set of everyday commonsense experiences which contribute to beliefs about the way the world behaves.
-a social response to a learning situation that searches to answer the question, "What does a teacher want me to say?"
-a private response to a learning situation that attempts to answer the question, "What do I really believe about an event"
-an emotional response that creates a set of associations that interact with interpretations of events.

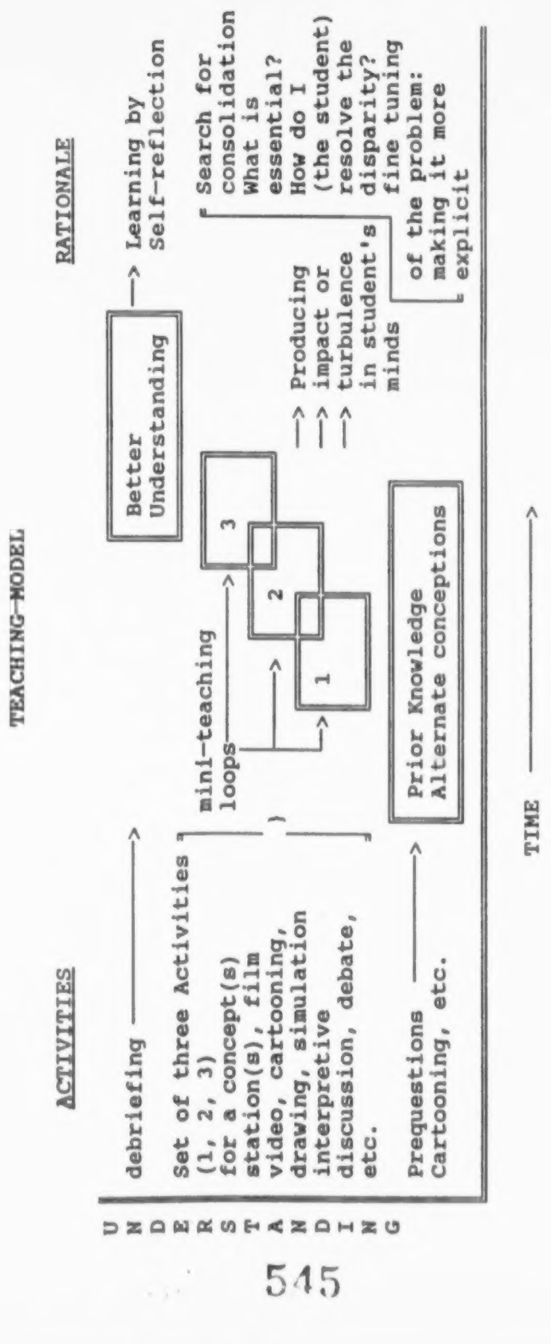
Perhaps a dialogue metaphor is useful in describing the kind of ways in which these components of the learner interact at any point of the sequence.

Douglas Hofstadter discusses the "Centrality of Slippability" in showing how connections are made in situations.

> Sideways connection like this, having nothing to do with causality, are equally much of the essence in allowing us to place situations in perspective to compare what actually is with what, to our way of seeing things, "might have been" or might even come to be.
>
> This ability, no less than intuitive physics, is a central aspect of what meaning is. The way that any perceived situation has of seeming to be surrounded by a cluster, a halo, of alternative versions of itself (underlining is mine), of variations suggested by slipping any of a vast number of features that characterize the situation, seems to me to be at the dead center of thinking.
>
> (Metamagical Themas: p.652)

The second component had to do with the logical sequence of the "Journal Method". On the next page there is a diagram of a teaching model which is designed to illustrate how the sequence used in the "Journal Method" highlights various requirements of the student over the course of a theme. At any moment, however, the student may be trying to draw conclusions, struggling with a disparity between his conception and an observation or thinking about how an idea may be tested with the apparatus at hand. The point here is that a kind of flow chart may sequence highlighted components of a lesson but that does not prevent the learner from being engaged in other parts of the sequence at any point.

The teaching model has a horizontal axis of time and a vertical axis of understanding. These do not have scales. The display shows three vertical divisions. The first division contains the activities in the "Journal Method". The second division shows time sequencing using a set of 5 boxes. In general a theme starts at the lower left box of prior knowledge and moves diagonally up through two or three interconnected sets of experiences or mini-teaching episodes which might contain micro-teaching components to reach the upper right objective of not complete but of better understanding. The last division contains a rationale for the proposed parts.


TEACHING MODEL
ACTIVITIES
RATIONALE
debriefing
Set of three Activities (1, 2, 3) for a concept(s) station(s), film video, cartooning, drawing, simulation interpretive discussion, debate, etc.
Prequestions Cartooning, etc.
mini-teaching loops
1
2
3
Better Understanding
Prior Knowledge Alternate conceptions
Learning by Self-reflection
Producing impact or turbulence in student's minds
Search for consolidation What is essential? How do I (the student) resolve the disparity? fine tuning of the problem: making it more explicit
UNDERSTANDING
TIME

SECTION FIVE- THE CONDITIONS FOR INTERPRETIVE-CONSTRUCTIVIST TEACHING

A list of environmental characteristics which contribute to interpretive-constructivist instruction was distilled from the class observation data and from reflective conversations between the observer and teacher involved in the study.

1. Students are in control of their own learning. The teacher's function is that of negotiator between the students' prior knowledge and school knowledge.
2. Students are allowed to express their ideas and views, and the teacher praises their contributions and seriously considers these views in his instructional activities
3. Students view the classroom as a "Forum" where each one is entitled to express his ideas.
4. Trust between teacher and students and among students is crucial.
5. Students are made aware that the teacher values their views and encourages open disagreement.
6. The teacher possesses a constructivist view of scientific knowledge. This means he sees science as a branch of knowledge in constant development; that theories are mind created and they are kept while they are useful, after which they can be replaced by other mind created theories.
7. The teacher views teaching as a creative activity and not just a prescriptive one.
8. The teacher guides and encourages students to be independent learners, and praises any progress made by students.
9. The teacher's talking is reduced to a minimum, while allowing more time for students to express their ideas.
10. The teacher encourages students to rephrase their ideas. It is important to provide sufficient wait-time for the development of the student's responses.
11. The teacher does not hesitate rediscussing a concept when he realizes that most of the class did not grasp it.
12. Monitoring the level of the class's comprehension of a concept is advisable.
13. The teaching pace is set according to the way the teacher perceives the students are grasping the concept.
14. The teacher never puts down students because of a wrong answer or an alternative conception. Even when the latter is completely different from the acceptable one, the teacher shows interest and encourage students to present their ideas.
15. The teacher reflects on all aspects of a lesson. This occurs during the lesson (reflection - in action) and after the lesson (reflection - on - action). He is open to implement changes which are products of his reflection.
16. The teacher provides the right context when introducing a new topic. A search is made for all possible materials related to the topic: reading materials, pictures, films, videos, field-trips.
17. Students are exposed to as many experiences as possible related to the topic, before discussing concepts.
18. If students are really in control of their own learning, they do not need the constant presence of the teacher in the classroom to do their work. The teacher is able to leave the room without changing the students' habit of work.
19. The teacher is tuned to the emotional and attitudinal mood of the class. If the class seems to be

tired or not interested, there is no point in getting involved in an abstract discussion, but rather to develop practical activities.

SECTION SIX - CONCLUSIONS AND EXTENSIONS

It was felt that the specific objectives of this case study had been accomplished.

1. The six generic teaching strategies were implemented as planned. Brain-storming and media were the ones most often used.
2. Several micro-teaching episodes were identified, which were clearly a product of interpretive discussions after a student had made public their conception.
3. Most of the students reacted positively to the mode of instruction and to the generic teaching strategies. That is, the strategies motivated students to do their work and they were eager to learn. These claims are based on the atmosphere of hard work and interest in learning noted by the observer, and the comments made by the students during the interviews or when answering the questionnaire.

In addition it may be of practical interest to other teachers that the method proved to be efficient and that the students excelled in a cross-grade final examination on the content involved. All curriculum requirements were met in the required time. In fact many enrichment questions were dealt with.

As an extension of the study another teacher of Junior High School science expressed interest in learning how to use the Journal Method. She was able to do so with considerable peer coaching. In fact she extended and improved the method with additional types of activities and slight modifications. She believed the method to be so successful for her that she has decided to keep using it.

The student teacher attempted to use the Journal Method in a teaching practicum with the same teacher at a later time. It was easier for him to organize the content for constructivist teaching than it was for him to deal with the students in a constructivist manner. One might conclude that the skills necessary for constructivist teaching must be learned. The student teacher's progress during several practicums suggests that it is possible to do so.

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Schon, D. (1983) The reflective practitioner:How professionals think in action. New York: Basic Books.

This case study has been written up in detail. If the reader is interested in obtaining a copy of the detailed report of approximately 150 pages length write to Dr. Gaalen Erickson of the Science Education department of the Faculty of Education at the University of British Columbia . A nominal fee covering the cost of reproduction will be assessed.

A STRATEGY TO DEAL WITH CONCEPTUAL AND REASONING PROBLEMS IN INTRODUCTORY ELECTRICITY EDUCATION

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1. Introduction

Over the last decade the teaching of science in secondary schools and especially the teaching of physics has been investigated in several Western countries. A lot of information has been attained about the levels of performance of pupils of different ages and backgrounds. A number of studies point out the difficulties secondary school pupils have in understanding scientific concepts and give insights into their ways of reasoning. The situation in the Netherlands is in no way better. Formal, one-way teaching methods seem to predominate, certainly in upper secondary classes but perhaps also in lower classes. We have come to recognize a number of conditions related to learning and teaching, which should be taken into account by teachers if they want to be successful in reducing conceptual difficulties and in modifying intuitive ways of reasoning.

The objective of our project on introductory electricity education is to construct a teaching approach which is inspired by information on (i) children's thinking in and motivation for physics, (ii) current developmencs in the theory of cognition and (iii) a new approach of the physics content itself.

In this paper we describe this new teaching approach and the first experiences with this approach in introductory electricity teaching in Form 2 of secondary education, focussed on two intuitive ideas namely 'the current consumption idea' and 'the idea of the battery as constant current supply'.

2. Theoretical background of the project

Following Driver and Oldham (1985) we agree with the three identified theoretical developments potentially fruitful for the construction of a new teaching approach. These developments concern (i) children's ideas, (ii) a constructivist view on learning and (iii) learning conceived as conceptual change. We briefly describe them here.

- It has become widely accepted that children already develop ideas and beliefs about the natural world long before they receive formal education. Certain characteristics of these so-called intuitive ideas have been identified. From a scientist's point of view the children's ideas are incoherent. The ideas are frequently used inconsistently both in time and across contexts. The use of language is imprecise and some of the ideas are firmly held and persistent despite science teaching. The ideas have been found with children of different ages and backgrounds (see Driver, Guesne and Tiberghien, 1985).
- Constructivist approaches to cognition and learning have a long history.
  Constructivist psychology assumes the existence of a learner's conceptual scheme which is used in interpreting and making sense of new situations and phenomena. For science teaching it is important to acknowledge and build on these conceptual schemes.
- However, learning is not only a development of existing concepts, it also has to do with a change of existing ideas and concepts. A number of conditions facilitate this conceptual change, such as: a developing dissatisfaction with existing ideas; but also the new concept has to be intelligible, plausible and fruitful; intelligible, in that it appears coherent and internally consistent; plausible, in that it is reconcilable with other views the pupil already has; and fruitful in that it is preferable to the old ideas on the grounds of elegance, parsimony or usefulness in daily life and school situations (Posner et al., 1982). We will use these theoretical developments in a more or less eclectic way, because they all deal with the process of learning and not explicitly with the process of teaching. If we want to stimulate the use of these constructivist ideas in real classroom situations, we have to develop a teaching strategy which is inspired by these theoretical developments. In the next paragraph we describe such a teaching strategy.

3. A new teaching approach: a constructivist strategy

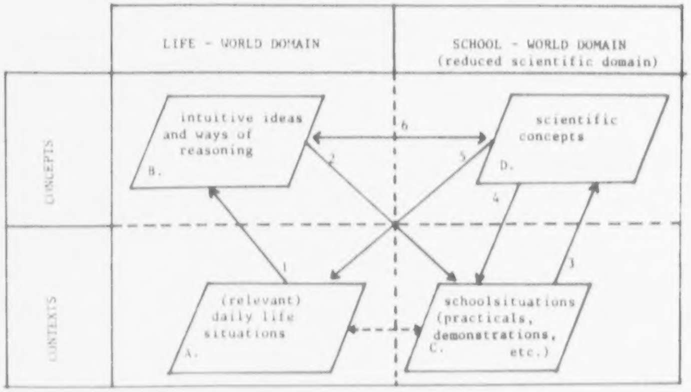
We plan to bring about a change in the teaching of electricity during the first years of secondary education. In doing so we wish to take account of the available research findings about conceptual and reasoning problems in the area of electricity, with special attention to intuitive ideas on current and voltage. During the teaching process we have followed the scheme outlined in figure 1.
In paragraph 3.1 we clarify how this scheme represents a strategy for education. The arrows 1 to 6 in this scheme represent the sequence in which we deal with the six phases of the strategy (A to F) distinguished during the teaching process.
Although this scheme forms a framework for the teaching process, it also provides us with new questions and choices to be made during the development of teaching materials. In paragraph 3.2 we discuss these questions and choices, because they are crucial for our evaluation of the effectiveness of the strategy. In itself the strategy gives no guarantee of good education.

3.1 **A strategy in six phases**

The strategy is an elaboration of ideas proposed by Nachtigall (1984, 1985), Nussbaum and Novick (1982) and Driver and Oldham (1985).
They all pay attention to different phases in the teaching process, like exposing alternative frameworks, creating conceptual conflict and encouraging cognitive accommodation. In addition to these ideas we want to pay attention to the contexts in which concepts should be developed and to the representation of the offered scientific concepts. The developed strategy consists of six phases, represented with A to F in the scheme of figure 1.

In the **orientation phase** of the strategy (**A** in the scheme) daily life situations will be brought into focus and recognized by pupils as something particular and meaningful. This part is designed to motivate the pupils for learning the topic by using relevant daily life situations as **an entrance** to the teaching-learning process (Wierstra, 1986). Taking into account the pupil's prior knowledge has not only to do with isolated concepts and intuitive ideas. A cognitive structure consists of three components: a conceptual component, an episodic component and a plan component (Boekaerts, 1982). Individual experiences related to conceptual knowledge form the episodic component of a cognitive structure; sequences of actions related to the episodic and the conceptual component form the plan component of a cognitive structure. Concepts stored in our memory are therefore always related to experiences and we assume that most intuitive ideas are related to daily life experiences.

figure 1   A strategy for education


LIFE - WORLD DOMAIN
SCHOOL - WORLD DOMAIN (reduced scientific domain)
CONCEPTS
CONTEXTS
intuitive ideas and ways of reasoning
B.
scientific concepts
D.
(relevant) daily life situations
A.
schoolsituations (practicals, demonstrations, etc.)
C.
1
2
3
4
5
6

By using daily life situations in physics education we expect:

(i) to activate existing ideas and stored experiences (see phase B).
(ii) to store the newly developed concept as a part of the conceptual component of a cognitive structure, related to a relevant episodic and plan component experienced in classroom situations (see phase E1).
(iii) a better transfer of the developed concept to other daily life situations used during the teaching process (see phase E2).

In the **elicitation and exchanging phase** of the strategy (B in the scheme) pupils make their ideas explicit, so bringing them to conscious awareness. This can be achieved by a variety of activities such as individual teacher-pupil interaction, small group discussions, classroom discussions or poster presentations. The product of this exchange of views is a variety of notions which describe or even explain the same phenomenon. Perhaps the initial equilibrium situation in the cognitive structure of pupils will already be disturbed during this exchanging process. Some of them might have ideas close to the scientific concepts to be developed. Others may adopt the intuitive ideas of others and reject their own ideas. Because the main objective in this phase is that pupils become aware of their own ideas, both as individuals and as a group, the teacher gives no physics input and abstains from any comment on the pupils' ideas.

In the **confrontation phase** of the strategy (C in the scheme) these ideas are tested against experience, either experimentally or by considering their implications. In this phase a conflict will be arranged between the offered school situation and the individual's cognitive structure. By school situation we mean a pupil experiment, a demonstration or a thought experiment purely developed for educational purposes. A school situation should be close to a daily life situation and forms in a sense a mediator between the scientific concepts and the daily life situation. The equilibrium situation in phase B of the strategy will be disturbed by means of a school situation.

In the **restructuring phase** of the strategy (D in the scheme) modifications of the cognitive structure are undertaken. In this phase the teacher plays an important role by giving hints or suggestions, by presenting analogies and models or by offering a "full" explanation for the pupils' new experiences in the school situation. This input of the scientific view and the possibility for pupils to explain the school situation for themselves, concludes this phase.

In the **application phase** of the strategy (E1 and E2 in the scheme) the new developed conceptual scheme in phase D can be recognized as productive and fruitful. The scientific concepts must be used in the school situations we were dealing with (phase E1) and in the daily life situations we started with and in various other daily life situations (phase E2) so that the extent (and the limits) of their application can be seen.

In the **review phase** of the strategy (F in the scheme) pupils become aware of the process that is going on. They are invited to reflect on the process of conceptual conflict and conceptual change by comparing their present thinking (phase D) with their intuitive ideas at the start of the process (phase B). The important role of their own ideas, concepts and ways of reasoning will be made explicit. In this phase it is possible to discuss the meanings and values of ideas and ways of reasoning in daily life compared to the concepts in a scientific domain. We agree with Solomon who says that 'the fluency and discrimination with which we learn to move between the two contrasting domains of knowledge - life world domain and school world domain - determines the degree and depth of our understanding' (Solomon, 1983).

3.2 New questions and choices during the development of teaching materials

It is obvious that the phases of the strategy that have been distinguished have to be translated into actions of pupils and teachers. During this translation process new questions come up and choices have to be made. The most important questions and choices during our translation of the strategy into an introductory electricity course of 15 lessons, concern:

(i) what kind of daily life situations in the context of electricity are known by the pupils, are relevant for them and give opportunities for orientation?

(ii) what are the (common) intuitive ideas contrasting firmly with the concepts current and voltage to be developed?

(iii) in what way do we want to present the concepts current and voltage?

Because we mainly describe here our experiences with the presented strategy in real classroom situations, we can only give a brief account of our so-called preparational research findings concerning the answers to the above mentioned three questions. By preparational we mean that we needed the answers before we could translate the strategy into teaching materials.

(i) Well-known context areas with a high preference among pupils are 'danger of electricity and protection against it' (94%, N=207, grade 9 and 10), 'sound and video apparatus' (87%) and 'electronics' (76%). Within the highly preferred context area of 'danger and protection' more than 70% of both girls and boys choose subtopics like: what to do in case of an accident involving electricity; when and why is a current or voltage dangerous; what is an electric shock (Licht, 1986a; see also Oldham a.o., 1986).

(ii) Based on the research of others (Shipstone, 1984; Closset, 1984; Cohen, 1983) we compiled a test to identify pupils' conceptual and reasoning problems before and after electricity instruction.
The same sorts of problems were presented in a number of questions, with slightly different circuits. This enabled us to see how consistent the ways of reasoning of the pupils were and whether these reflected certain thought patterns.

We identified **four main problem areas** (Licht, 1986b; Kuiper a.o., 1985):

1. the pupil's idea of current consumption in a bulb and a resistor.
2. the pupil's idea that a battery always gives (or sometimes produces) a constant current, independent of the particulars of the circuit.
3. local and sequential ways of reasoning in series and parallel circuits. Instead of a way of reasoning where all parts of a circuit are interrelated and influence one another, many pupils think, for instance, that a change in a circuit has only local or 'downstream' consequences. Also many pupils have the idea that at a branching point the current is always equally divided between the branches, independent of the electric components in these branches.
4. the high preference for using the concept of current rather than the concept of voltage and the lack of discrimination between these two concepts.

(iii) Following Posner we agree that newly developed concepts should be intelligible, plausible and fruitful. This can be achieved by using metaphores, analogies, models and metaphysical meanings and concepts (Posner et al., 1982). We mention here just one of our points of criticism on their theory of conceptual change, which is important in answering question (iii). In speaking about analogies and models as factors influencing the conceptual change, Posner makes no demands upon the intelligibility, plausibility and fruitfulness of these factors. One can argue that a model should meet the same requirements as the new concepts. Otherwise the pupils mistake the one analogy for the other or are not aware which analogy they are allowed to use in a certain situation. Also the model should be representable in various ways such as through verbal and symbolic representations and in real materials, diagrams and pictures.
We therefore developed a consistent model for electricity teaching in secondary education based on the concept of electron concentration (EC), inspired by publications of others (Coombes and Laue, 1981; Härtel, 1984; Walz, 1985; Steinberg, 1985). This EC concept acts as a germ-concept from which both the concept current and the concept voltage can be derived. The minus pole of a battery has a high EC, the plus pole a low EC. The main characteristic of the battery is that the difference in EC between the two poles will always be constant, thus independent of the circuit connected to the battery. A wire connected to a pole of a battery gets the same EC as this pole. It is the battery that produces a new distribution of electrons, always keeping the difference in EC between the poles constant. After connecting wires from the poles of a battery to a resistor, electrons will move

through the resistor from the high EC to the low EC, because the repulsive electrostatic force of the high EC is greater. The battery will fill up the high EC by removing electrons from the low (plus pole) to the high EC (minus pole).

Summarizing our model: caused by the constant differences in EC's, electrons can move through the circuit from a high to a low EC.

We can use this model in a fruitful way in all the circuits we encounter in secondary school electricity education. We worked out various representations of this model: (i) verbal, (ii) with wooden blocks and marbles representing the battery, resistors and electrons, (iii) symbolic. We are preparing a representation by a computer simulation.

Using this model we can present the concepts current and voltage in a concrete way: current is moving electrons (marbles) in the circuit; voltage is the difference in electron (marble) concentration between two points of the circuit.

Looking back to the four identified conceptual and reasoning problems (see (ii)) we have reasons to expect that the developed model with electron concentrations will also contribute in solving these problems:

- problem 1: current consumption can be replaced by current as moving electrons from minus to plus pole.
- problem 2: the battery gives no constant current but a constant difference in electron concentration, thus a constant voltage. The current will depend on the ohmic value of the resistor that separates the concentrations.
- problem 3: because of the electrostatic repulsive force the different electron concentrations in a circuit depend on one another. The electrostatic force has no preferential direction, it acts both 'up-' and 'downstream'. So by changing a circuit, not only the local electron concentration will change but also the concentrations 'up-' and 'downstream', and through that the division of voltages will change.

- problem 4: reasoning in terms of electron concentrations and thus in terms of voltages gets a more central place in solving problems. Voltage as well as current has to do with electrons, but voltage emphasizes the more static aspects of electrons, current the more dynamic aspects.

4. The developed teaching materials

The purpose of this paragraph is to give an outline of the developed written materials for the first 15 lessons on electricity. The central theme in the developed unit is: why is a power point dangerous and a battery not? (see par. 3.2 (i)). In answering this question we have to develop the concepts current and voltage.

Because we apply the strategy for the first time, we focus its use on the first two of the above mentioned four problem areas i.e. 'the current consumption idea' and 'the idea of the battery as constant current supply'.

We want to reduce these two problems by making use of all six phases (A to F) of the strategy. Both other problem areas i.e. 'local and sequential reasoning' and 'the lack of discrimination between current and voltage' are dealt with in a more implicit way by presenting and applying the model with electron concentrations. This means that we only use the phases D and E of the strategy to reduce these two problems (see figure 2).

In this way it is possible to compare the effects of the total strategy, applied to reduce the first two problems, with the effects of only the phases D and E of the strategy, applied to reduce the other two problems. In figure 2 we present an overview of the lessons planned for the different phases of the strategy in relation to the four problem areas. To produce conceptual conflict with respect to 'the current consumption idea' and 'the constant current idea' we confront the pupils with experiments of current measurement both in daily life situations with a power point (demonstrated by the teacher) and in school life situations with a battery and bulbs (pupils' experiments). The conclusions from these experiments should be that: a. the current has the same magnitude on both sides of a bulb or a resistor;

b. the magnitude of the current depends on the particulars of the circuit, in other words a battery is not a constant current supply.

figure 2 A plan for 15 lessons

Number of lessons*	The six phases of the strategy (A to F)	Conceptual and reasoning problems involved
5	A. **orientation** B. **elicitation & exchange** C. **confrontation**	· current consumption idea · constant current idea
2	D. **restructuring** by introducing the new model	· current consumption idea · constant current idea · local, sequential reasoning · discrimination voltage-current
7	E. **application** by using concepts and ways of reasoning in school situations (series and parallel circuits; changes in a circuit) and daily life situations (danger of electricity: protection against it)	
1	F. **reviewing** the pupils own ideas - with special attention to the ideas expressed in lessons 1 to 5 - in relation to the new scientific concepts	

* each lesson lasts 50 minutes, with two lessons per week

5. Preliminary research findings

With respect to the effects of the strategy we focus our research on the possible conceptual changes in problems on predicting and explaining the functioning of simple DC-circuits. We here present only preliminary results, because until now our qualitative research findings refer to only one class and one teacher and our quantitative research findings refer to three classes (including the above mentioned class) and three teachers in the experimental group with a mean age of the pupils of 14.6 years. The qualitative data are gathered on audiotape during the teaching process. The quantitative data are gathered with one test administered to an experimental and a control group on three moments: just before, just after and five months after teaching the subject.

First we present and discuss some **qualitative results**.

(i) The initial period of five lessons with hardly any physics input from the teacher made the pupils feel insecure (phases A to C of the strategy). Although the teacher explained the purpose of these lessons, he was frequently invited to give the correct answers, and not only to collect the pupils' ideas and to confront them with ideas of others or with an experiment. Certainly this attitude can be attributed to their inexperience with this way of teaching. On the other hand we should not neglect the pupils' fear that they did not learn enough or that they learned the wrong things during these five lessons.

(ii) We used an intermediate test after these five lessons only with one class. This revealed that some changes had already taken place in the pupils' ideas on 'constant current' and 'current consumption'. In particular 'the idea of a constant current source' was changed to the scientific view (60% constant current thinkers changed to 15%, N=19).
'The idea of current consumption' had not changed significantly after these five lessons (50% changed to 42%). We explain this negative result by the absence of a conceptual conflict in a situation where we planned the conflict should arise. Using two ammeters with a pointer indication for measuring the current resulted in almost two-thirds of the cases pupils still saying that the readings on either side of a bulb would not be exactly the same. Many pupils still spoke in terms of current consumption, although some of them had to admit that the consumption was less than they expected. Using just one ammeter for measuring the current to either side of a bulb, was not accepted as a solution because most of them did not spontaneously understand the difference between the two circuits they had to build.
After the intermediate test we made another attempt in the same class to change 'the current consumption idea' by using two digital ammeters one on each side of a bulb in an inaccurate measuring range.

Now the two meters displayed the same current in numbers. Here for the first time we observed that the current consumption idea really was confronted by a pupil's experiment. Often pupils made remarks like 'okay, current is not used up. But a bulb gives light and heat, so something must be used up'. The solution for this problem was not given yet. Some lessons later the energy concept was introduced as a possible solution.

(iii) An example of avoidance of conceptual conflict had to do with a table on dangerous current indications which was part of the curriculum materials. From this table the pupils could see that a current of 40 mA might lead to unconsciousness for a human being. Just before looking at these data, they measured a current of about 200 mA in a circuit with a battery and a bulb. More than half of the pupils indicated that the battery is not perilous, because the data in the table have to do with 'power point current' and not with 'battery current'. The goal was that pupils would wake up to the fact that current is not the only quantity necessary to predict the danger of a source. But for most pupils the need for a new concept, i.e. the concept voltage, was not very convincing.

(iv) The last qualitative result we mention, is the general appreciation for the teaching materials, especially for the model with electron concentrations. The representation with wooden blocks and marbles proved to be intelligible, plausible and fruitful not only in the restructuring phase of the strategy (phase D) but also in predicting and explaining all kinds of daily life and school situations during the application phase (phase E).

Secondly we present and discuss some **quantitative results**. The quantitative data are based on the pupils' answers to questions in the pretest, the posttest and the delayed posttest. The pretest was administered two weeks before the electricity education started, the posttest just after the series of 15 lessons and the delayed posttest five months later.

The experimental group consisted of 70 pupils. To have the possibility of comparing the results of the experimental group with the results achieved in more traditional electricity education, we administered the test to three different 'control' groups, one group before instruction in electricity, one just after and one some five months after studying the subject. We have to admit that the use of three different 'control' groups can only be conceived as a rough way of comparing the effects of the new strategy with the effects of the electricity education in general in the Netherlands. Yet there is another problem concerning this comparison. The experimental group used 15 lessons for the development of the concepts current and voltage to a qualitative level, whereas the control groups used on average 15 lessons for the development of the same concepts with the emphasis on quantitative aspects. However, most of the questions in the test can be characterized as qualitative questions. This we have to take into account in comparing the results of the experimental and the control groups. Figure 3 gives an overview of the quantitative data.

figure 3 Quantitative findings concerning the four problem areas (in %)

The four areas of conceptual and reasoning problems (see par. 3.2 (ii))	Experimental group N=70			Control groups		
	Pretest	Posttest	Delayed posttest	N=205 Pretest	N=232 Posttest	N=307 Delayed posttest
1. Current consumption idea	54	11	14	52	37	43
2. Constant current idea	33	11	14	40	33	31
3. Local/sequential reasoning	75	39	54	69	51	64
4. No discrimination between voltage and current	95	52	67	96	66	66

Analyzing the results of the experimental group only, we conclude:

- the use of all six phases of the strategy (A to F) seems to give a more or less permanent solution for the problem areas 1 and 2. Based on the additional qualitative results we have reasons to believe that the conceptual change for 'the constant current idea' already has taken place during the first 5 lessons with demonstrations and pupils' experiments (phases A to C). The conceptual change for 'the current consumption idea' just started during these 5 lessons and continued during the introduction and application of the new model with marbles and marble concentrations (phases A to E).
- although the improvement from pre- to posttest for the problem areas 3 and 4 is better than in area 2, the post- and delayed posttest results are disappointing. The model with electron concentrations, applied in the phases D and E of the strategy to deal with the problem areas 3 and 4, certainly contributes to changes in ideas. But these changes are in no way stable cognitive structures. The theoretical and abstract way in dealing with these two problem areas, directed to explaining phenomena, seems to be rather plausible and fruitful for just a short period.

Comparing the results of the experimental group with the results of the control groups, we conclude:

- the new teaching approach leads to significantly ($p < 0.01$) better results on the areas 1 and 2 than more traditional electricity education.
- the use of the model with electron concentrations leads only temporarily to significantly ($p < 0.05$) better results on the areas 3 and 4 than more traditional electricity education.

Both the composition of the control group and the mixture of results caused by the confrontation approach and by the presented model mean that we have to be careful in our interpretation of the results. Nevertheless we regard these preliminary findings as promising signs that we are looking for a solution in the right direction.

6. Proposals for improvement

We suggest improving the existing teaching materials by using all six phases of the strategy (A to F) for the other two problem areas too. This change only requires an extension of the application of the strategy.

However, there should be quite a change in the strategy itself. Until now we have dealt with the strategy in terms of concepts on two levels, an intuitive level and a theoretical, explaining level. The gap between these two levels is big and cannot be bridged by presenting abstract models, analogies and formulae, which force pupils to speak a new, scientific, language.

Implicitly we not only criticize here our own developed strategy, but also strategies proposed by others (Driver and Oldham, 1985; Hashweh, 1986). In all of these strategies much attention is paid to intuitive ideas and the aspect of confrontation. But there are hardly any useful suggestions for the ways we could develop the scientific concepts - phase D in our strategy.

Our results show that many pupils can learn the scientific language, but only for a short period. After some months the number of explanations in terms of electrons and electron concentrations in the problem areas of local and sequential reasoning is far less than just after the series of lessons. To bridge the gap between the intuitive ideas and the theoretical concepts we propose the use of an **intermediate level**, which enables pupils to describe phenomena both in a qualitative and a quantitative way. We call this intermediate level the level of **analytical simplification**. On this level pupils have to discover rules and regularities in their own guided observations: by guided we mean that the teacher points out which quality has to be observed or which quantity has to be measured in relation to a given object. On this level pupils should: (i) classify, compare and relate objects based on one or more characteristics - for instance a bulb shines brighter with two batteries behind each other than with one battery; (ii) classify, compare and relate concepts based on one or more characteristics of these concepts - for instance the current through a bulb is greater when the voltage is increased. The language on this level is not scientific in all its aspects, because certain characteristics of the concepts are still hidden. For instance, the pupils are allowed to say that the voltage is 'used up' in a circuit, after measuring voltages in a series or parallel circuit. The intermediate level leads to **separate empirical generalizations** concerning the relations between concept characteristics.

On the intuitive level there is no logical network of concepts available and pupils do not discriminate between concepts. Their expressions are based on common sense, daily life language, prejudices or a strong visual structure concerning the observed phenomena.

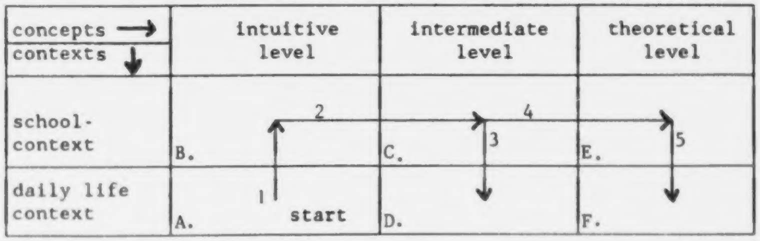
On the intermediate, describing level some generalizations are already available. So there is a weak network of concepts to argue about and describe phenomena.

On the theoretical, explaining level a full network of concepts is available to explain the relations between objects with the help of generalizations. A scientific explanation then consists of some conditions (facts) and one or more generalizations followed by a logical conclusion which corresponds with the relation that has to be explained.

Transferred to our electricity education it is clear that the abstract model with electrons and electron concentrations belongs to the theoretical level. The introduction of this model seems useless, if pupils do not spend enough time on describing all kinds of experiences with static electricity and simple circuits in terms of brightness of bulbs, voltages and currents.

Based on the experiences with the first version of the strategy we propose a second version, taking into account the above mentioned three levels of concepts. Our future research activities will be based on this second version. It has the following aspects in common with the first version (see figure 4): daily life and school situations (vertical component in scheme) and intuitive ideas and scientific concepts (horizontal component in scheme).

figure 4 A strategy for education - second version



The arrows again represent the sequence in the teaching-learning process. Compared to the first version a new aspect in this strategy is an intermediate level of concepts linked with both situations in the school world domain and in the life world domain. Because we can only present an outline here, we just give the names of the phases distinguished in the strategy:
A. orientation and exchanging phase; B. confrontation phase; C. (empirical) generalization phase; D. application phase (1); E. rule-generalization and rule-integration phase; F. application phase (2).

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ALGORITHMIC vs HEURISTIC STRATEGIES
in COMPUTER SIMULATED PROBLEM SOLVING

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COMPUTER SIMULATION,
ALGORITHMS AND HEURISTICS IN EINSTELLUNG EFFECT

The ground-breaking work on human problem solving by Newell and Simon (1972) focuses on information processing and computer simulation to explain the behavior of human problem solvers (and of computers). In a final section entitled "Epilogue" they note that phenomena such as functional fixity and the Einstellung effect "must surely be included within the scope of a comprehensive theory. No extensive reanalysis of these phenomena from an information processing viewpoint has been carried out, but they speak to the same basic phenomena, so should yield to such an explanation" (p. 872). The present report is an attempt at reanalysis of data on the Einstellung effect in terms of information processing and computer simulation. It describes some of our attempts to adapt ideas of computer simulation of problem solving behavior to the study of the Einstellung effect in water-jar problems.

In particular, we are interested in comparing algorithmic and heuristic approaches to problem solving and their relation to Einstellung effect. An algorithm may be characterized as a procedure for formula that guarantees the solution to a given problem or type of problem. A heuristic is a problem solving strategy, often derived from experience, that serves as a helpful rule of thumb in finding a solution, but does not necessarily lead to a solution. The clear distinction between the two approaches begins to blur when one speaks of a "faculty algorithm" (cf. Roberts, p. 544) that may or may not lead to a solution. Indeed, in the past decade increasing attention has been paid to "Probabilistic algorithms-ways of solving problems that almost always work but have a small but definite chance of being worng" (Kolato, in Science, 2 March 1984, p. 917; also 4 June 1976, p. 989).

In our usual Einstellung effect experiments (Luchins, 1942), one method, the so-called set-inducing or

Einstellung method, worked in almost all of the problems (all but one in the basic setup). Subjects often became so set on this method that they failed to solve the non-conforming problem (or problems), and they overlooked neater, shorter, or more direct methods of solutions in several of the problems. A redeeming feature of the set-method, viewed as a probabilistic algorithm, was that it was applicable to most of the problems. Moreover, it might be faster to adhere to one method than to try various heuristic approaches. We were interested in comparing algorithmic and heuristic approaches with respect to time of solution, strength of Einstellung effect, and recovery from Einstellung as evidenced by relative frequencies of solutions and of failures. We were also interested in possible order effects of having one or another approach first and the influence of different series of problems.

General Procedure

Computer simulation brings to mind machine simulation of human problem solving. The present series of experiments took a different track. We asked what would happen if human beings were asked to simulate a computer and were programmed according to an algorithmic or to a heuristic approach. All experiments were individually administered.

EXPERIMENTS WITH USUAL PROBLEMS

The exploratory experiments were done with a modification of the usual series of water-jar problems (Luchins, 1942). In the prototype experiment an illustrative problem was followed by five set-inducing or Einstellung (E) problems. If the three jars in each problems are called A,B, and C respectively, then the method which solves each of the E problems is given by B-A-2C. Then there were five test problems to test for the

effects of Einstellung. The first two were critical problems solvable by the oft-repeated method as well by direct (D) methods, either A-C or A+C. The next problem (Problem 9) was an extinction task solvable by A-C but not by the set method. The tenth and eleventh tasks were again critical problems. In the present exploratory experiments the following changes were made in the problems. For purposes of comparison, the same critical problem was presented both as the illustrative task and as the tenth problem. Also, a twelfth problem was added at the end, (Given 40, 118, 18, get 62), which could not be solved by any of the previous methods but could be solved by a new method, 2A-C.

In the usual experiment the subjects were told orally that their task was to figure out on paper how to obtain a required volume of water, given certain empty jars for measures. In the present exploratory experiments the instructions were presented on printed cards and their nature depended on whether an algorithmic or heuristic approach was used.

The instruction cards for the algorithm approach read as follows:

1. Fill the center jar.
2. Pour from the center jar into the left-hand jar, filling the left-hand jar.
3. Pour from the center jar into the right-hand jar, filling the right-hand jar.
4. Empty the right-hand jar.
5. Pour again from the center jar into the right-hand jar.

The instruction cards for the heuristic method read as follows:

1. Look to see if any one jar by itself can give you the correct solution.
2. Look to see if any two jars by themselves can give you the correct solution.

3. Look to see if any three jars by themselves can give you the correct solution.
4. Look to see if any one jar used two or more times with any other jar used once can give you the correct solution.
5. Look to see if any one jar used two or more times with the other jars used once each can give you the correct solution.

An inspection of the steps reveals that the algorithm program is designed for the B-A-2C solution, while the heuristic program can lead to any of the solutions appropriate to the problem, and, finally, to the B-A-2C solution.

Experiment 1. This experiment was administered to 20 female college students, half of whom received the algorithm program first and then the heuristic program a few days later; this constitutes condition A1-H2. The other subjects received the heuristic program a few days before the algorithm program; this constitutes condition H1-A2.

To illustrate the results, we present in Table 1 the percentages of responses as well as the time of response to the test problem which was presented both as the first and as the tenth problem (Given 18, 48, 4, get 22).

Regardless of whether it was the first or second administration of the problem, the heuristic approach yielded more direct (D) solutions, fewer Einstellung (E) solutions, and fewer failures (F) of the problem and required less time than did the algorithm program. On the average, with the heuristic approach the time of solution was 23.3 seconds and 5.4 seconds for the first and tenth problems; the corresponding times were 46.5 and 12.7 seconds for the algorithm program, twice as long or more. For the first and tenth problems combined, on the average the heuristic approach yielded 90 percent direct solutions, 2 percent E solutions, and 8 percent failure while the

algorithm approach yielded 15 per cent direct solutions, 72 per cent E solutions, and 13 percent failure.

Replication of the experiment with ten more subjects, seven of them males, again showed that the heuristic program produced more direct solutions and fewer failures and took less time; e.g., on the average the heuristic program required 23.7 and 5.7 seconds for the first and tenth problem respectively, while the algorithm program took 50.5 and 16.8 seconds respectively or over twice as long.

Table 1 also presents the percentages of responses to the test problems for 50 subjects (including those whose results were referred to already), most of them college students. Again the results seemed to depend more on the type of program than on whether it was the first or the second presentation of the problems. Of particular interest are the results in Problems 9 and 12 which could not be solved by the B-A-2C method. With the algorithm approach there were 64 and 52 percent failures of Problem 9 on the first and second presentations; with the heuristic approach there were 12 and 28 percent failures respectively. For Problem 12 the algorithm program yielded 96 per cent failure on each presentation while the heuristic program showed 64 and 56 percent failure respectively. Direct solutions for the five test problems averaged 14 percent for the algorithm program and 53 percent for the heuristic program. In short, the heuristic approach consistently yielded more direct solutions and fewer failures.

Statistical analysis of the data in Experiment 1 revealed significant differences between the algorithmic and the heuristic approaches. The differences in D solutions and in E solutions between the two approaches, which ranged from 60 percent to 90 percent for the first problem and for its representation as the tenth problem, were significant at high levels of confidence. Thus, for the first and tenth problem combined, the mean difference between the two approaches of 75 percent D solutions and of 70 percent E solutions, each attained statistical significance at better than the .001 level of confidence. For Problem 9, which could not be solved by the E method, the difference of 52 percent D solutions (and failures) between the two approaches when each was the first presentation, attained statistical significance at the .01 level; the corresponding difference of 24 percent, when each approach was the second presentation, was significant at the .02 level. For Problem 12, which required a new method of solution, the difference between the two approaches in solutions (and failures) of 32 percent and of 40 percent on the first and second presentation respectively each attained statistical significance at the .01 level.

It is of interest that a set for the B-A-2C method was developed in both the heuristic and algorithm programs, judging by the large percentage of E responses to the first test problem (60 and 92 per cent respectively); but the set was more readily broken under the heuristic approach.

Experiment 2. In this experiment, which used the usual eleven water-jar problems, four conditions were compared.

- H: The heuristic approach as described before (five instruction cards).
- HG: The heuristic approach was used together with the instructions to the subject to try and generalize a rule that seemed to form a pattern of solution.
- AG: Solutions to the first two problems (which included the use of the B-A-2C method) were illustrated and the subject was asked to generalize a rule of solution.
- AR: In addition to being shown the answers to the first two problems, the subject was explicitly given the formula or rule B-A-2C.

The experiment was conducted individually with 196 subjects, with about an equal number studied under each condition. In order to keep constant the practice in the use of the B-A-2C method, we considered the responses of the 115 subjects who used only this method in all five E problems, thus excluding subjects who solved any of these problems by other methods or who failed any of them. Because the results were very similar for Problem 7 and 8 and, similarly, for Problems 10 and 11, the results were combined. Table 1 shows that in Experiment 2 the number of subjects who solved Problems 2-6 by the B-A-2C method increased monotonically from Conditions H to HG to AG to AR. Likewise, the percentages of E responses to the critical problems, and of failures of Problem 9, tended to increase monotonically, while the percentages of direct responses tended to decrease monotonically in successive conditions. Thus the least Einstellung effect was developed under the heuristic condition H and the most under condition AR where the subject was explicitly given the formula or rule B-A-2C.

Statistical analysis was undertaken of the differences in results between the H(heuristic) and the AR (algorithm plus rule) approaches. For Problem 7 and 8 combined, the difference of 19 percent in D(and in E) solutions between the two approaches was significant at the .01 level. For Problem 9, the extinction task, the difference of 37 percent in D solutions (and in failures) was significant at the .01 level. For Problem 10 and 11 combined, the differences of 21 percent in D solutions and of 25 percent in E solution were significant at the .02 level.

EXPERIMENTS WITH NEW PROBLEMS

While an instruction card in the heuristic approach asked if any one jar by itself gave a solution, this method did not lead to solution in the usual water-jar problems. New series of problems were therefore devised in which the filling of one jar did give the solution in the test problems (see Table 2). In one of these series, called the E series, the only solution common to the first six problems was the B-A-2C method. In the other series, called the D series, each of the first six problems could be solved by B-A-2C, by B-2A, by A-C and by C, the filling of one jar. Although the test problems differed in the two series, they followed the same format. The problems and their possible solutions are listed in Table 2. In each series Problem 9 could be solved by A-C and by C, but not by B-A-2C; Problem 12 could be solved only by B-A-2C and not by the direct methods(and thus might test the development of a possible set for the direct methods); and Problem 13 could be solved only by 2A-C and not by any of the previously used methods.

In order to emphasize the computer simulation aspects, the instructions were changed to include the following:

"Today I am asking you to imitate an electronic computer that has been programmed to perform certain operations. We want to know how a human feels when he has to act like a computer. You will do only as you have been programmed. I will give you, one at a time, a series of problems. You are to solve each one by using the programmed instructions which I shall give you. If you do not follow the programmed instructions, I shall pull the plug on the computer, that is, I shall stop you and insist that you follow directions as given. Each problem is to be solved by reading aloud the first card, following the instructions on it, and so on. For each problem you have to go through the entire set of these instructions."

Subjects were required to wait 10 to 15 seconds between instruction cards. A maximum time limit of two and one half minutes was allowed per problem except for the first problem for which more time was allowed. (Anticipating the results, we note that in every experiment the subjects seemed to be annoyed that they had to wait 10 to 15 seconds between instruction cards and that they had to read all the cards.)

The instruction cards for the two programs were as follows:

Heuristic:
1. Begin. Inspect the problem.
2. Can you solve the problem using only one jar?
3. Can you solve the problem using only two jars?
4. Can you solve the problem by some combination of all three jars?
5. Fill the center jar and measure out with other jars.
6. Check your answer.

Algorithm:
1. Begin. Fill the center jar.
2. Pour from center jar to fill left-hand jar.
3. Pour from center jar to fill right-hand jar.
4. Empty right-hand jar.
5. Pour from center jar to fill right-hand jar again.
6. Check your answer.

Experiment 3. For 20 college students both the program and the series of problems were varied. A subject first received one of the series, either Problem Series E or D, under the heuristic program and immediately afterwards received the other series under the other program. The results are summarized in Table 3, where H1-D denotes that the first presentation was the heuristic program with the D series and A2-E indicates that the second presentation was the algorithm program with the E series, etc. (In this table, C refers to a one-jar solution and EX to failures brought about by attempted use of the E method.) In the first six problems of the D series, the C method, the filling of one jar, was always used under the heuristic program, whether it was the first or second presentation.

Thus, the subjects apparently were not influenced by the preceding experience which they had had with the algorithm program in the E series. Indeed, in Problems 7 and 8 of both series, all subjects used the C method under the heuristic program, whether it was the first or second presentation, and they continued to use it whenever it was available as a solution. Apparently the heuristic approach tended to work against the development of a set with the D series where the one-jar solution solved the first eleven problems.

Under the algorithm program, subjects used the E method until the ninth problem, where some of them, despite the instructions, shifted to a direct method and in a few cases continued to use it in subsequent problems. The total number of failures on both presentations of the last problem, which required a new method, was 9 for the subjects who had the algorithm program first with the E series (A1-E), 7 for those who had the algorithm program first with the D series (A1-D), 5 for those who had the heuristic program first with the E series (H1-E), and only 3 for those who had it with the D series (H1-D). Thus, failures of the last problem were fostered by the algorithm approach and by the E series. This was also attested to by the numbers of E responses, plus failures due to the use of this method, which were as follows for all the problems combined: A1-E:63, A2-E:60, A1-D:58, A2-D:58, H2-E:38, H1-E:34, H2-D:8, H1-D:1. It is seen that E responses plus failures tended to decrease monotonically from the A-E to the A-D to the H-E and H-D conditions and were usually less in the second presentation than in the first presentation.

Statistical analysis of the data in Experiment 3 for all the problems combined consistently yielded significant differences at better than the .01 level. When the D series of problems was used, whether in the first or second presentation, there were 85 percent C solutions under the heuristic program and only 8 or 9 percent such solutions under the algorithmic program, for a difference of 76 percent. When the E series of problems was used, whether in the first or second presentation, C solutions were 38 percent with the heuristic approach but averaged only 3 percent with the algorithmic approach, for a difference of 35 percent. With the D series, E responses averaged only 3 percent under the heuristic program and 81 percent under the algorithmic program for a difference of 78 percent. With the E series of problems, E responses were 49 percent for the heuristic approach and still 81 percent for the algorithmic approach, for a difference of 32 percent. Thus C and D responses, the one-and-two-jar solutions, were consistently and significantly higher under the heuristic than under the algorithm program, regardless of whether the E or D series of problems was used, or whether they were given in the first or second presentation. Concomitantly, E responses were consistently and significantly higher with the algorithmic approach.

The mean time (in seconds) per problem was as follows: A1-E:49.3, A2-E:46.4, H1-E:40.8, A1-D:35.2, H2-E:31.6, A2-D:30.6, H1-D:20.8, H2-D:18.8. Thus more time tended to be taken by the algorithm than by the heuristic program, by the E series than by the D series, and by the first presentation than by the second presentation.

The new problems were also used with ninth grade junior high school students. Preliminary studies showed that the children tended to be upset when the program did not fit a problem, e.g., under the algorithm program when a problem was not solvable by B-A-2C. Therefore, at the onset of the session in each program, the subject was given a tilt or reject card to use to reject a problem which did not fit the program, just as a computer might do. However, subjects did not always reject such a problem, in some cases because they did not realize that it did not fit the program: e.g., they applied B-A-2C to the ninth problem, writing 58-24-12-12=12 for Series E or 27-10-5-5=5, without checking the arithmetic. On the other hand, the tilt card was sometimes inappropriately used when the subject had made an arithmetical error.

The time per problem under a given condition was more varied than for the subjects of the previous experiments and seemed to depend on the particular child's speed in carrying out the arithmetical operations. This may help to explain why no consistent time differences were found among the various conditions.

Experiment 4. In one study done with 40 junior high school students, five boys and five girls were tested under each of four conditions. Each student was tested under one program, either the algorithm or the heuristic, and received the E series followed immediately by the D series or the other way around. Under the algorithm program the children obeyed the instructions more strictly than did the college students; they usually used the B-A-2C method even when they realized that it did not lead to a solution. Under the heuristic program the children were more variable than the college students and used relatively more two-jar solutions and also more three-jar solutions other than B-A-2C than did the college students.

Under the algorithm program most errors resulted from the use of the B-A-2C method. Unfortunately, a record was not kept of which failures under the heuristic program resulted from this method. Therefore, the summary of results in Table 3 does not specifically list EX responses but it does give failures (F). The table also gives T responses, which refer to any three-jar solution other than by the E method. The table shows that under the algorithm program there were virtually no differences in results in Experiment 4 between the E and D series. E responses for all the problems ranged from 80 to 82 percent under the A1-D, A1-E, A2-D and A2-E conditions. Under the heuristic program the first six problems were solved mainly by direct methods in the D series and (perforce) mainly by B-A-2C in the E series while the test problems of both series were solved mainly by direct method. Thus, the children did not tend to develop a set under the heuristic program. This program, particularly in conjunction with the D series, tended to foster direct solutions and to cut down on failures. This trend becomes very clear when the numbers of different kinds of responses for all the problems are considered in the order: H2-D, H1-D, H2-E and H1-E. Thus C responses decreased (91, 89, 44, and 41) and E responses increased monotonically (7, 7, 42, and 48) when considered in this order.

The percentages of responses in Experiment 4 to all the problems combined were subjected to statistical analysis. There were 69 and 70 percent C responses in H1-D and H2-D respectively but 32 and 34 percent such responses in H1-E and H2-E, for a statistically significant difference of about 36 percent in each case ($p<.01$). While C responses averaged 51 percent under the heuristic approach, there were no one-jar responses under the algorithmic approach, making for a highly significant difference ($p <.001$). There were 15 percent D responses for H1-D and H2-D but slightly less, 11 and 8 percent, for H1-E and H2-E respectively.

While D responses averaged 12 percent for the heuristic approach, there were less than 1 percent two-jar solutions under the algorithmic program, making for a significant difference ($p<.01$). Under the heuristic approach, E responses averaged 35 percent for the E series but only 5 percent for the D series, for a significant difference ($p<.01$). While E responses averaged 20 percent under the heuristic program, there were 80 percent E solutions for each series of problems under the algorithmic program, making for a highly significant difference between the two approaches ($p<.001$). Under the heuristic program, failures to solve the problems averaged 10 percent for the D series and 20 percent for the E series ($p<.05$). Failures averaged

15 percent with the heuristic approach; they were only slightly higher, 18 or 19 percent, under the algorithmic program. Thus there were sharp and significant differences in responses between the two approaches with respect to C, D and E solutions, but only small and insignificant differences with regard to failures.

Comparison of the results for H2-D and H1-D show that solutions involving one jar (C) and two jars (D) were slightly higher and failures (F) were lower on the second presentation than on the first presentation. Results were less consistent for the E series. As in the previous experiments, whether the presentation was first or second was less important than the nature of the series and the nature of the program.

Experiment 5. Ten other junior high school students received the heuristic program one day and the algorithm program two days later. In each session they received the E series and then the D series. (Variations in the order of the programs and the series remain to be done.) The quantitative results were similar to those in Experiment 4, as can be seen in Table 3. The data in Experiment 5 for all the problems combined show that under the heuristic program, one-jar or C solutions were 26 and 58 percent for the E and D series respectively ($p<.01$) and two-jar or D solutions were 11 and 29 percent respectively ($p<.01$). Also attesting to the influence of the series of problems were E solutions which under the heuristic program were 49 percent for the E series but only 5 percent for the D series ($p<.001$). In contrast, under the algorithmic program, there were few differences in responses to the E and D series, each yielding no one-jar or two-jar solutions, about 80 percent E solutions and about 18 percent failures due to the E method. Differences under the two approaches averaged 42 percent for C responses, 20 percent for D responses, 54 percent for E responses and 13 percent for failures due to the E method, with all statistically significant ($p<.001$ for the first three differences and $p<.01$ for the last). It seems that the preceding experience with the heuristic program did not significantly influence the results in the algorithm program.

Of interest are the children's reactions to the two methods. When asked which approach they preferred, 7 of the 10 children said that they preferred the heuristic program, claiming that they like to do things their own way rather than being told what to do, that they do not like to do things the same way every time, and that the heuristic program usually took less time. "I like to decide how to solve the problems. I would rather make mistakes with my own method than be sure with someone else's method," and "The program makes easy problems unnecessarily difficult" were some of the criticisms of the algorithm approach. The three subjects who expressed preference for the algorithm approach said that "the other way made me nervous."

One of the children said that whether he prefers to use an algorithm for solving problems or heuristics depends on the problems; for difficult problems he prefers to use a pattern that has worked before while for simpler problems he likes to experiment. When asked their reaction to having to operate like a machine, nine of the ten subjects said that they would not like to operate as a machine. Both the quantitative and qualitative data showed similar patterns for boys and for girls.

DISCUSSION

Einstellung Effects, Algorithms, and Heuristics

Einstellung effects have been described in the literature in terms of both algorithms and heuristics (Atwood & Polson, 1976; Bourne, Dominowski, & Loftus, 1979; Bourne, Ekstrand & Dominowski, 1971; Gardner & Runquist, 1958; Hassett, 1984; Scandura, 1977). In particular, the use of the oft-repeated method in the water-jar problems has been cited as a prime example of algorithmic knowledge. Thus, Greeno (1973) distinguishes between two kinds of knowledge, the first referring to relational and conceptual information, and the second to knowledge in the form of operations or rules. "The clearest examples [of the second kind] are rules for operating on values of variables, as in mathematical formulas such as 'mass = density x volume,' or the rule 'X = B - A - 2C' in the Luchins (1942) experiment. I shall refer to this second kind of knowledge as algorithmic knowledge" (Greeno, 1973, p. 114).

Greeno offers an interpretation of our 1942 work as well as a conjecture that is relevant to the present variations. He hypothesizes that one factor of productive thinking in problem solving is the extent to which the solution plan of a problem has to be constructed from components retrieved from memory, rather than retrieved whole.

> This [factor] provides a way of interpreting the studies of Luchins (1942) on mechanization in problem solving. At the beginning of a series of water-jar problems a subject presumably has to construct a solution plan by finding a linear combination of the jar sizes that gives the desired amount of water. Having constructed an algorithm, and finding that it works for a few problems, the subject apparently has the strategy of trying that algorithm first for each new problem. This strategy seems reasonable enough, but it does lead to the subject's using the rather cumbersome algorithm B less A less 2C for some problems where an easier algorithm such as A less C also works. If the subject went through the process of constructing a solution plan for each problem in the series, rather than the simpler process of retrieving the previous solution plan from memory as an algorithm, it seems likely that the simpler solution plan would be found by most subjects (Greeno, 1973, p. 117).

The last cited sentence predicts that if the subjects were looking for a solution plan in each problem, as presumably they were under the heuristic approach, then most subjects would find the simpler solution plans, that is, the direct solutions. Our results support this prediction. In every experimental variation there were significantly more direct solutions with the heuristic approach than with the algorithmic approach.

Use of a method which worked in preceding problems, even when it leads to Einstellung, has also been described as a heuristic, indeed a valuable heuristic. Thus, Newell, Shaw and Simon (1957, 1958) programmed their Logic Theorist to follow the previously most successful path. This is pointed out by Anderson (1975) after he describes Einstellung effects in the water-jar problems.

> Trying paths in order of past success will reduce the probable number of paths that must be tried, although it will occasionally lead to Einstellung effects. Einstellung (Luchins, 1942) is the application of a previously successful plan in a situation in which it is no longer optimal. Einstellung has most frequently been studied by means of water-measuring problems. ...

> Persistence in the old, less efficient plan constitutes a demonstration of the Einstellung effect. The Logic Theorist was programmed to start with the previously most successful path, and, as would be expected, it occasionally did show Einstellung effects. Despite occasional Einstellung effects, however, this is a very valuable heuristic (Anderson, 1975, p. 276).

Anderson also notes, in discussing the strategy of starting with the shortest path, that Newell, Shaw and Simon (1957, 1958) programmed their Logic Theorist not to consider paths that led to complex expressions. In our experiments, the strategy of starting with the shortest path conflicts with the strategy of following the previously successful plan since the latter leads to a more complex expression. In other words, using the Einstellung method, whether it be the result of algorithmic thinking involving the rule B - A - 2C, or the result of following the heuristic strategy of using the previous successful plan, conflicts with the strategy of starting with the shortest path.

It has been noted that following the previously successful plan would reduce the probable number of paths that must be tried (Anderson, 1975, p. 276). In our experiments there were fewer paths that had to be tried if one immediately applied the B - A - 2C method in the first five problems, where the direct methods did not work, or even in those critical problems where there was no one-jar solution but two-jar and three-jar solutions. It was reasonable to expect that having fewer paths that had to be tried would be accompanied by a decrease in time. Hence it was reasonable to expect that use of the B - A - 2C method would take less time than would use of the heuristic strategy that called for scanning the problems to see if one, two, or three jars were needed. However, the experiments in which time scores were kept consistently showed that less time was required for the heuristic approach than for the algorithmic approach.

Einstellung has been characterized as "the set which immdiately predisposes an organism to one type of motor or conscious act" (Warren, 1934). Our results are often described in the literature in terms of the more general concept of set. For example, Hayes (1978) notes that our 1942 investigation dealt with set which "may be defined as a readiness to perceive or act in particular ways in a situation ... If you expect to be presented with a problem of a particular type, you may be set to use a particular solution procedure" (p. 70). He characterized functional fixity, a term used by Duncker (1945), as an inability to perceive that an object which is known to have one use may be used for an entirely different purpose. Although we did not use this particular term, the results of our basic study and other studies (Luchins & Luchins, 1950, 1959) have been characterized in the literature in terms of "functional fixedness" (e.g., Rosenthal & Zimmerman, 1978). Thus, Blumenthal (1977) writes:

> But again, there is a negative side to highly developed automaticities. It is what Duncker (1945) and Luchins (1942) named "functional fixedness." Well-developed automaticity may at times block creativity or blind us to new solutions for problems. Our patterns of attention can become too well set on particular schemes (p. 171).

Blumenthal continues by noting that the experimental study of the activity of problem solving can reveal attentional patterns or cognitive styles. He offers as an example investigations by Bruner, Goodnow, & Austin (1956) with concept-identification tasks, in which subjects were free to select items in order to test problem-solving hypotheses about a set of attributes (size, shape, color). Two general characteristics of most problem solvers emerged; the investigators described one of these as a tendency to stress focusing, and the other as a tendency to stress scanning. Focusing strategy involved concentrating on one attribute of a given item as an example of a category and looking at subsequent items to determine if they fit the category. Scanning involved forming a hypothesis or hypotheses about the solution and then dealing with one hypothesis at a time (successive scanning) or with several hypotheses (simultaneous scanning). In the particular problems that Bruner and his associates used, focusing proved to be a more effective strategy than scanning.

It has been argued (Laughlin, 1973) that focusing and scanning are not mutually exclusive strategies but are two dimensions of cognitive processing that can overlap or operate simultaneously. Thus, the strategy of focusing on one aspect of an example at a time is similar to "successive scanning" (Blumenthal, 1977).

There are some ambiguities involved in applying the terminology of focusing and scanning to the present experiments. Nonetheless, the strategy of focusing, say, on the largest jar or on the B - A - 2C method, seems to be more applicable to the algorithmic condition and the strategy of scanning to the heuristic conditions, where the task was to test, one at a time, the hypotheses as to whether one jar works, whether two jars work, or whether three jars are needed. In our experiments, unlike those of Bruner, Goodnow, and Austin (1956), scanning seemed to be a more effective strategy than focusing. Some possible explanations may lie in the differences in the nature of the tasks and the hypotheses; their tasks did not lend themselves as readily to Einstellung effects and their

subjects were not instructed about the order in which hypotheses were to be tested.

It is also of interest to look at the experimental situation in terms of the frame (or framework) system developed by Minsky (1975) and elaborated by Winograd (1975). Minsky, who adapts a psychological approach to artificial intelligence, and recognizes that common sense reasoning is not necessarily mathematical or logical reasoning, believes that the frame system is a possible approach for representing common sense knowledge in a computer. A frame system may be a collection of definitions whose details vary with the switching of frames (or purposes or goals or contexts), so that some details become optional or more or less important.

> For example, a frame for 'birds' might include feathers, wings, egg-laying, flying and singing. In a biological context, flying and singing are optional; feathers, wings, and egg-laying are not. ... If you are walking in the woods, the importance of 'flying' in your bird frame is substantial. If you are in Antarctica its importance is minimal (Kolata, in Science, 24 September 1982, p. 1237).

It can be said that under the heuristic program there was a switching of frames with the appearance of the test problems, so that the largest jar became optional and the B - A - 2C method less important than it had been in the set-inducing problems. The algorithm program did not foster the switching of frames, but called for adherence to one frame system in which the B - A - 2C method was paramount. In general, Einstellung effects might be regarded as the consequences of adherence to a frame when the shifting of frames would be more appropriate.

CONCLUSIONS AND IMPLICATIONS

A redeeming feature of the B - A - 2C method, viewed as an algorithm or a "probabilistic algorithm," was that it was a ready, fixed response which solved most of the problems. Hence, it might have been expected to be more efficient than the heuristic approach that required surveying each problem to see if its solution required one, two, or three jars. In particular, the algorithmic approach might have been expected to lead to more solutions and to faster solutions, particularly of problems solvable by the B - A - 2C method. However, the results were quite counter to these expectations. Consistently, the heuristic approach yielded faster solutions, even of problems solvable by the B - A - 2C method, and yielded significantly more solutions, more direct solutions, and more novel solutions than the algorithmic approach. Even when both approaches led to the development of a set or Einstellung, there was faster recovery from the Einstellung under the heuristic approach. These trends held in all five experimental variations, those done with the usual water jar problems as well as those done with a new series of problems, and also held for college students as well as for junior high school students. Moreover, when the children were later questioned as to their preference, most of them replied that they preferred the heuristic approach.

The implications of the findings for education are that it may be more advisable to teach heuristics rather than algorithms. The results speak against the supposed advantages of teaching rules by rote for fast, ready responses. Yet a call for such teaching seems to underlie the cry for a "return to basics" and for more learning and practice of rules, say, in arithmetic (as in some of the speeches by Secretary of Education William Bennett). Our results suggest that there are dangers in such teaching and learning, that heuristics may make for more effective and resourceful problem solving, and may be better liked by the students.

There are also implications for cognitive psychology and its applications, which are currently much in vogue. It has been said that cognitive psychology began with computers, that its main tool is the information processing model, and that its main thesis is that the processes that go on inside the human mind can be described in the same terms as those used to describe the processes that go on inside a computer (Mayer, 1981). But computers are usually programmed in accordance with one or another algorithm. "There is a big emphasis in modern computer science on comparisons of algorithms" (Roberts, 1984, p. 23). Our findings suggest that an information processing model based on computers programmed according to algorithms would be a one-sided and unduly narrow model. It would be too narrow to encompass processes that describe the workings of computers that use heuristic strategies and certainly too restrictive to describe the workings of the human mind (cf. Davis, 1973, pp. 61-62).

Why was the heuristic approach so effective in yielding direct and novel solutions? One explanation may be that it called for the subjects to examine the problems, to survey them, in order to see whether one, two, or three jars were needed for solution. In contrast to the survey or overview of the problems favored by the heuristic approach, the algorithmic approach tended to focus the subject on the big or center jar, the B jar, and to subtract automatically from it once with the left jar, A, and twice with the right jar, C. It was such a narrow view of the problem that led to some of the failures of the extinction task under the algorithmic approach. It would be of interest to see how specific instructions to survey the problem first would influence the operation of the heuristic and algorithmic approaches for human problem solvers and for computers.

The instructions to use one, two, or three jars to solve the problems was also used in some of our other experiments as part of the initial instructions (Luchins, 1942). But it seemed that people, unlike computers, forgot the instructions as they became set to use the three-jar response, B - A - 2C. An experiment in which these instructions tended to be more effective coupled them with the instructions to find as many solutions as possible in each problem (Luchins and Luchins, 1959). It would be of interest to see what would happen to human problem solvers, and to computers, if such instructions to encourage variability were coupled with the algorithmic and the heuristic approach. Would they lead to more varied solutions or to finding all possible solutions? A facet of problem solving that is grossly neglected in education is the seeking of many solutions or of all possible solutions, or of many approaches to a problem, rather than seeking one particular solution or resting content after any one solution has been found.

In conclusion, an algorithm is a response to a preplanned sequence of events but the human organism, and a "smart computer," must be able to respond to unplanned sequences. The world around us never exactly repeats itself. The human learner must have flexibility, the ability to deal with a changing environment. The present results suggest that a heuristic approach may be more appropriate than an algorithmic approach for meeting a changing problem situation.

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TABLE 1. RESPONSES TO USUAL TEST PROBLEMS a

Percentages of Responses and Mean Time of Responses to Repeated Test Problem in Experiment 1 (20 Ss)

Problem		1				10			
Response		D	E	F	Time	D	E	F	Time
Condition	Ss								
M1	10	70	0	30	27.1	100	0	0	5.0
A2	10	10	60	30	45.7	30	70	0	10.3
A1	10	0	80	20	47.2	20	80	0	15.0
M2	10	100	0	0	19.4	90	10	0	5.7

Percentages of Responses to Test Problems in Experiment 1 (50 Ss) b

Problems		7			8			9		10			11			12	
Responses		D	E	F	D	E	F	D	F	D	E	F	D	E	F	D	F
Condition	Ss																
M1	25	32	60	8	48	44	8	88	12	80	16	4	68	24	8	36	64
A2	25	0	92	8	4	88	8	48	52	20	76	4	12	84	4	4	96
A1	25	0	92	8	12	84	4	36	64	16	80	4	8	88	4	4	96
M2	25	24	60	16	32	48	20	72	28	68	24	8	68	20	12	44	56

Percentages of Responses to Test Problems In Experiment 2 (115 Ss)b

Problems		7-8			9		10-11		
Responses		D	E	F	D	F	D	E	F
Condition	Ss								
M	25	34	66	0	84	16	60	34	6
M6	28	34	66	0	71	29	60	38	2
A6	28	23	75	2	61	39	46	50	4
AR	34	15	85	0	47	53	39	59	2

a. The three jars in a problem are denoted by A, B and C. The D response refers to a direct method: A-C or A+C; E refers to the Einstellung or E method: B-A-2C; F refers to failure to solve the problems.

b. The percentages are for those 115 of the 196 subjects who solved the five E problems by the E method.

TABLE 2. NEW WATER-JUG PROBLEMS AND SOLUTIONS

a Problem No.	Series E A	B	C	Get	Solutions	b Problem No.	Series D A	B	C	Get	Solutions
1	11	25	5	4	B-A-2C	1	28	70	14	14	B-A-2C/C/A-C
2	21	127	3	100	B-A-2C	2	46	115	23	23	B-A-2C/C/A-C
3	14	163	25	99	B-A-2C	3	22	55	11	11	B-A-2C/C/A-C
4	18	43	10	5	B-A-2C	4	8	20	4	4	B-A-2C/C/A-C
5	9	42	6	21	B-A-2C	5	38	95	19	19	B-A-2C/C/A-C
6	20	59	4	31	B-A-2C	6	18	45	9	9	B-A-2C/C/A-C
7	16	40	8	8	B-A-2C/C/A-C	7	4	10	2	2	B-A-2C/C/A-C
8	14	35	7	7	B-A-2C/C/A-C	8	24	60	12	12	B-A-2C/C/A-C
9	24	58	12	12	/C/A-C	9	10	27	5	5	/C/A-C
10	26	65	13	13	B-A-2C/C/A-C	10	36	90	18	18	B-A-2C/C/A-C
11	12	30	6	6	B-A-2C/C/A-C	11	70	175	35	35	B-A-2C/C/A-C
12	6	21	4	7	B-A-2C	12	12	42	8	14	B-A-2C
13	40	118	18	62	2A-C	13	20	59	9	31	2A-C

a. The three jars in a problem are denoted by A,B, and C. The solution B-A-2C is the Einstellung or E method; C denotes a one-jar solution: filling the C jar; A-C denotes a two-jar solution; 2A-C is the new solution required by the final problem.

b. In the D series, besides the methods listed, B-2A solves all problems except Problem 9 (the extinction task), Problem 12 and Problem 13.

Table 3. Responses to New Test Problems a

Percentages of Responses and Mean Time
of Responses in Experiment 3 (20 Ss)

Prob.		1-6				7-8			9			10-11			12			13			All Problems					Mean
Resp.		C	E	EI	F	C	E	EI	C	D	EI	C	E	EI	E	EI	F	D	EI	F	C	D	E	EI	F	Time (Sec)
Cond.	Ss																									
M1-D	5	100				100			100			100			20		80	60		40	85	5	2		9	20.8
A2-E	5		97	3			90	10	60		40		100		100			40	60		5	3	82	11		46.4
A1-E	5		97	3			80	20		20	80		100					20	80			3	80	17		49.3
M2-D	5	100				100			100			100			40	20	40		100		85		3	9	3	18.8
M1-E	5		83	10	7	100			100			100			80		2	60	40		38	5	45	8	5	40.8
A2-D	5		93	7			100		100				100		80	20		40	60		8	3	82	8		30.6
A1-D	5		97	3			100		80		80	20	80		100			20	80		9	2	80	9		35.2
M2-E	5		97	3		100			100			100			100			40	60		38	3	52	6		31.6

Percentages of Responses in Experiment 4 (80 Ss)

Problems		1-6					7-8				9			10-11				12			13		All Problems				
Responses		C	D	E	T	F	C	D	E	F	C	D	F	C	D	E	F	E	T	F	D	F	C	D	E	T	F
Cond.	Ss																										
M1-D	10	83	12	3		2	80	20			80	20		75	25			50		50	10	90	69	15	5		12
M2-E	10		5	58	7	30	90	10			90	10		85	10	5		60	20	20	20	80	34	8	32	5	22
M1-E	10		7	68	3	22	75	15	5	5	90	10		85	15			60	10	30	30	70	32	11	37	2	18
M2-D	10	85	15				80	20			80	20		80	15	5		60	30	10	20	80	70	15	5	2	7
A1-D	10		2	95		3			95	5			100			95	5	90		10		100		1	80		19
A2-E	10			97		3			95	5			100			100		100				100			82		18
A1-E	10			92		8			100				100			100		100				100			81		19
A2-D	10			98		2			100				100			90	10	90		10		100			82		18

Percentages of Responses in Experiment 5 (10 Ss)

Prob.		1-6						7-8				9			10-11				12			13			All Problems					
Resp.		C	D	E	T	EI	F	C	D	E	EI	C	D	EI	C	D	E	EI	E	EI	F	D	EI	F	C	D	E	T	EI	F
Cond.	Ss																													
M1-E	10		5	80	3	3	9	65	10	25		80		20	65	30	5		100			30	20	50	26	11	49	1	5	8
M2-D	10	70	30					70	30			70	30		65	30		5	70	20	10	40	30	30	58	29	5		4	4
A3-E	10			97		2	2			95	5			100			90	10	100				100				81		18	1
A4-D	10			95		3	2			100							95	5	100				100				82		17	

The three jars in a problem are denoted by A, B, and C. The response C refers to a one-jar solution: filling the C jar. D refers to a direct solution: A-C or 2A-C; E refers to the usual three-jar solution: B-A-2C; T refers to a three-jar solution other than by the E method; EI refers to a failure resulting from use of the E method; F refers to any other failure of solution.

TOWARD A CONCEPTUALIZATION OF A REFLECTIVE PRACTICUM IN SCIENCE TEACHING

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Introduction

This paper presents an analysis of supervisory dialogue that occurred in a science teaching practicum. Of particular interest to this investigator is the sort of practicum experience that engages a student teacher and a supervisory teacher in discussion about how pupils might interpret science classroom events. Accordingly, the study has two aims: (1) to conceptualize what reflective thinking about science teaching entails, and (2) to derive from the supervisory practice of an expert science teacher the elements of a reflective practicum--that is, a practicum that is focussed on possible meanings that pupils construct from science classroom events. The analysis reported here comprises a preliminary study of a project that investigates Schön's (1987) ideas about a reflective practicum in professional education, together with a constructivist perspective on the teaching and learning of science, with an aim to see what it looks like when a constructivist perspective comes to bear on the reflective stance of a student teacher of science. The first part of the paper presents a constructivist perspective on teaching and learning science, together with its implications for science teacher education. Second, Schön's (1983, 1987) ideas regarding "reflective practice" and the professional education of "reflective practitioners" are presented in preparation for the statement of the problem and research questions of the study. Finally, preliminary data analysis is illustrated with excerpts from two supervisory discussions held between a student teacher of Grade 10/11 physics and his supervisory teacher.

Children's Science: A Constructivist Perspective

Over the past decade there has been a great deal of science education research dealing with the ways in which children make intuitive sense of natural phenomena (Driver & Erickson, 1983; Driver, Guesne & Tiberghien, 1985; Erickson, 1979; Gilbert & Watts, 1983; Osborne & Wittrock, 1983). It is generally accepted that children form their own ideas about natural phenomena long before they arrive in the science classroom, and that their ideas may be quite different from currently accepted scientific views. The term "children's science" has evolved in the literature that investigates the intuitive ideas that children hold about natural phenomena (Osborne & Freyberg, 1985). Many researchers have observed that children's science often remains uninfluenced, or is influenced in unanticipated ways by science teaching (Erickson, 1983; Erickson & Aguirre, 1985; Gilbert, Osborne & Fensham, 1982; Osborne & Freyberg, 1985; Smith & Anderson, 1984).

Information that has been collected about children's science has been accompanied by increasing attention to a constructivist view of science teaching and learning. Central to this perspective is the premise that individuals construct their own meaning of new information and ideas on the basis of their existing knowledge; learning is not a matter of passively taking up "static" information. A second premise underlying the constructivist view is that learners are "purposive" beings (Magoon, 1977). Thus, the constructivist account of learning is concerned with the "intents, beliefs and emotions of individuals as well as their conceptualizations, and recognizes the influence that prior experience has on the way phenomena are perceived and interpreted" (Driver & Oldham, 1985, p. 2). One dimension of thoughtful science teaching may be the capacity to recognize that children do construct knowledge and beliefs in science. This dimension may lead a teacher to consider the possible interpretations of science classroom events that the learner might make. A thoughtful science teacher would likely seek information about the learner's current understanding of particular scientific ideas. As Osborne and Wittrock (1983) argue, "Considerable emphasis in research, in curriculum design, and in teaching at all levels needs to be placed on the nature and detail of children's views of the world and meanings for words used in science. Teaching needs to take fully into account pupil perceptions and viewpoints and, where appropriate, to attempt to modify or build on, but certainly not ignore children's ideas" (p. 492).

Fensham (1983) has proposed six "new objectives" for science education based on a general constructivist view of knowledge. Among them is, "to make explicit the world views of natural phenomena that students hold and to relate these to world views held now and in the past by scientists" (p. 7). While the intent of this objective is quite acceptable, it does not capture the dynamic way in which children's conceptions and beliefs influence their perceptions and constructions as they evolve in the classroom. A characteristic of what this investigator would describe as thoughtful science teaching may be described in terms of a disposition that teachers have for "seeing" the world of the classroom from pupils' points of view.

From a constructivist perspective, much learning in science involves children coming to hold new and more powerful ways of conceiving scientific events and concepts--ways that are consistent with our intellectual heritage of scientific inquiry. Yet, the learning of these "orthodox" scientific concepts may be likened to what Kuhn (1962) refers to as a "paradigm shift." Thus, educational theoreticians who have adopted a constructivist perspective have begun to speak of learning in terms of conceptual change, a general model of which is briefly presented in the following section.

The Conceptual Change Model

Posner, Strike, Hewson and Gertzog (1982) and Hewson (1981) have proposed a general model of conceptual change, drawing primarily from philosophy of science. The conceptual change that takes place during learning is likened to a "paradigm shift" (Kuhn, 1962) in the advancement of theoretical science, whereby a particular set of ideas is replaced by another more powerful one. In order for conceptual change to occur, several conditions must be met. First, there must be a dissatisfaction with existing conceptions; the learner must have a store of anomalies or puzzles that cannot be resolved with his or her current conceptual repertoire. Second, a new conception must be "intelligible," that is, the learner must be able to make sense of it. Third, the new conception must be "plausible"--it must be reconcilable with other existing concepts, and it must be believable. Finally, the new conception must be "fruitful" in that it solves a previously unsolved problem, or it opens up new territory for inquiry.

Hewson and Hewson (1984) have suggested a number of teaching strategies that are inherent in the conceptual change model. The main categories of strategies include "diagnosis"--the gathering of information about pupils' existing knowledge regarding a particular conception or phenomenon; "integration"--the linking of a new conception to existing conceptions when they are reconcilable; and "exchange"--the superseding of an existing conception with a new, irreconcilable conception, brought about by creating conflict among the pupil's existing conceptions, then resolving the conflict with the new one.

Appropriately, Hewson and Hewson (1986) have derived from their analysis important implications for science teacher education. They suggest that science teachers ought to be, "aware of the role played by students' existing knowledge in understanding new material; convinced of the need to use conceptual change teaching strategies when students' existing conceptions conflict with those being taught; and able to plan and perform teaching actions which give effect to these strategies" (p. 5).

Osborne, Bell and Gilbert (1983) have derived from a constructivist perspective on science teaching similar implications for teacher education. They advocate that "teachers should have a greater knowledge of, and respect for, children's science" (p. 12), and they call for a teacher education program that would support the development of such knowledge.

But while the case that science teacher educators should adopt these aims has been convincingly argued on theoretical grounds, there are several reasons why a constructivist perspective on teaching and learning cannot neatly be put into practice, either in preservice or inservice teacher education. Hewson and Hewson (1986) remind us of the complexity involved in this matter: a constructivist perspective on teaching and learning depends upon particular conceptions of the nature of science, of learning, and of teaching. With respect to the latter, for example, Hewson and Hewson show that preservice and inservice teachers are likely to hold alternative conceptions of teaching, some of which conflict with the conceptual change approach to teaching science. In a similar vein, Osborne, Bell and Gilbert (1983) focus on the teachers' knowledge of scientific ideas, noting that much of what is taught in the name of science is in fact similar to children's science: the teaching of science also depends upon the individual teacher's knowledge of science and his or her conceptions of the nature of science.

This study begins with the following orientation, or set of objectives for science teaching and science teacher education: (1) a thoughtful science teacher will recognize that children do construct meaning of classroom events, (2) such a teacher will have a disposition for attempting to

"see" science classroom phenomena from pupils' perspectives, and (3) a thoughtful science teacher will thus be in a better position to teach children about orthodox science. The following section begins to explore the matter of bringing this orientation to bear on science teaching practicum.

Educating the Reflective Practitioner

By way of an introduction to Schön's ideas, it will be useful to draw upon an analogy he has used to point to a dilemma that exists in professional education. Schön (1983) refers to this dilemma as one of "rigor or relevance" (p. 42). He imagines the topography of professional practice to consist of a hard, high ground overlooking a swamp. The hard, high ground is comprised of well-formed theoretical problems that can be solved by applying the methods of science. In the swamp below there are the important, but messy and difficult problems of practice--problems that require artistry for their definition. In thinking about professional practice, one has two courses of action. One can remain on the hard, high ground where it is possible to be rigorous in solving problems, but where the problems are relatively unimportant to practice. The other alternative is to descend into the swamp below where the problems are relevant, but where one cannot be rigorous in any way that he or she can describe.

Schön draws upon Glazer's (1974) distinction between the "major" professions and the "minor" professions, the major professions being somewhat closer to the hard, high ground than the minor ones. In major professions, such as medicine, engineering, or agronomy, there are zones where practitioners can function as technical experts. However, expertise in the minor professions, such as education, social work, and divinity, relies on experience, trial and error, intuition, and "muddling through" (Schon, 1983, p. 43). The dilemma of rigor or relevance afflicts the minor professions dramatically, and it is conspicuous in the preparation programmes of these professions, affecting teachers and students alike.

What is puzzling for Schön is that some people are very good at dealing with the swampy, uncertain problems of practice. He argues that it is difficult for us to account for what these people know how to do because the universities that prepare them tend to subscribe to a particular view of professional knowledge inherited from positivistic philosophy. Schön (1983) refers to this view of professional knowledge as "technical rationality"--the view of professional education grounded in the belief that the teaching of propositional knowledge should precede the development of skills in its application.

Uncertain situations of practice do not fit the model of technical rationality partly because the problems that are confronted in practice do not come as "givens." Rather, problems that are of concern to the professions must be *made* out of uncertain situations. The process by which one gets to a well-formed problem is not in itself a technical problem. Unique situations often do not fit the cases in the book. And, when unique cases do not fit the categories of established theory or technique, then established theory and technique cannot be applied to them. "When we set the problem, we select what we will treat as the 'things' of the situation, we set the boundaries of our attention to it, and we impose upon it a coherence which allows us to say what is wrong and in what directions the situation needs to be changed. Problem setting is a process in which, interactively, we *name* the things to which we will attend and *frame* the context in which we will attend to them" (Schön, 1983, p. 40, Italics in the original).

Yet, technical rationality is built into the normative curricula of professional schools. The tradition of these curricula is to first instruct students in the propositional knowledge pertaining to their field, and then follow it with a practicum. What is neglected is the importance of experience in learning a profession, together with *opportunities for developing the habit of reflecting about, i.e., "reframing" (Schön, 1983), experience*.

Schön approaches the matter of professional education from a different perspective. He asks not how we can apply science to the problems of practice, but how we can discover in the work of practitioners what it is that they know when they are being competent. If we can develop an understanding of what practitioners know when they are being competent in situations of uncertainty, uniqueness and conflict, then we will surely have a direction in researching how competence can be transmitted in professional education.

To begin, Schön points to the kind of knowledge that a competent practitioner displays in action--the non-logical processes that are manifest in recognition of pattern and making sense of complexity. Here, Schön draws extensively from Polanyi's (1962) notion of tacit knowledge, and he develops the concept of knowing-in-action to refer to the spontaneous, intuitive awareness that practitioners bring to professional competence. The phenomenon of carrying out a sequence of actions without having to think about them is of central importance. One's ability to do so does not depend on the description of the sequence. Rather, one's ability to recognize patterns in situations of uncertainty and uniqueness, and to act efficaciously in those situations, depends on one's capacity to *frame* problems. In doing so one is drawing upon a repertoire of past experience and ways of apprehending that experience, both of which lead to an ability to *reframe* problems in the light of the information obtained from the practice setting. Schön refers to this process as "reflection-in/on-action," that is, the "conversation" that takes place between the practitioner and the uncertain situation. Reflection-in/on-action, then, comprises the artistry of professional practice.

A question of interest to this study is how a novice teacher might learn, or develop the disposition of reflecting on classroom events from pupils' perspectives. To deal with the matter of professional education for reflective practice in general, Schön (1987) has looked toward what he refers to as the "deviant position" of the arts, and he has drawn upon the architectural design studio and the conservatory of music to develop a model of artistry in professional education. He then asks how we might marry the deviant position of the arts with the legitimate role and function of science derived from universities to assist in rethinking the role of practicum in professional education. To that end, Schön has put forward the notion of a "reflective practicum."

The Reflective Practicum

The core of professional education consists of learning how to think about practice while engaged in practising. While this notion is certainly not a new one, Schön (1987) has provided a set of categories that seems to promise new understandings of practicum in professional education. It will be useful to begin with a few introductory comments about Schön's ideas and then proceed to a brief description of two component processes about which a reflective practicum might unfold: telling and listening, and demonstrating and imitating.

First, the practicum setting is regarded by Schön as one that provides a "virtual world," that is, a world that represents the practice world, but which allows the student to experiment at lower cost. The student teaching situation might be seen as consisting of times when the beginning teacher is functioning in a virtual world--those times when he or she is engaged in planning or critique of instruction with the supervisory teacher, and times when he or she is functioning in the practice world--during actual classroom teaching. Second, the practicum situation of

learning by doing should involve the supervisory teacher as a helper--someone who is sensitive to issues and concerns of becoming a teacher (Schön refers to the practicum supervisory as a coach). Third, the competence to be learned in practicum is a design-like competence; it is holistic, it involves relection-in-action, and it is characterized by the framing of indeterminate situations. This competence is the sort of thing about which one could say either you get it as a whole, or you don't get it at all. The beginning of practicum, therefore, is likely to be confusing and mysterious since the competence to be learned cannot simply be told to the student in a way that he or she could at that point understand. Even when the coach is very good at describing what he or she knows, the likelihood of the student grasping the meaning that the coach has in mind is very small. Under these circumstances some students discover that they must learn the required competence for themselves; they cannot be taught it.

At the beginning of a practicum, communication between the student and the coach seems nearly impossible. Yet, as time passes by, some students and coaches begin to communicate effectively. They begin to finish each other's sentences, or leave sentences unfinished, confident that their essential meanings have been grasped. Of course, some students never do understand what the coach is talking about, and some coaches never get through to their students. Nevertheless, many succeed in crossing an apparently impassable communications gap to achieve some degree of convergence of meaning.

Schön's conception of reflection-in/on-action is particularly useful when considering the nature of the dialogue that occurs between a student and a coach (supervisory teacher). The coach must at first try to discern what the student understands, what he or she already knows how to do, and where the difficulties are. These things must be discovered in the student's initial performances. In response, the coach can show or tell, that is, demonstrate some part of the process that he or she thinks the student needs to learn, or, with questions, advice, criticism or instructions, describe some feature of the craft. The coach models actions to be imitated, and experiments with communication, testing with each intervention both the diagnosis of the student's understandings and problems, and the effectiveness of his or her own strategies of communication. The student tries to make sense of the coach's demonstrations and descriptions, testing the meanings that have been constructed by applying them to further attempts to display skilfull practice. In this way the student reveals the sense he or she has made of what has been seen or heard.

Schön has proposed three models to describe the general features of a reflective practicum: joint experimentation, follow me, and hall of mirrors. The model of joint experimentation takes an exploratory, analytic stance: the coach joins the student in experiment in practice, testing and assessing the student's ways of framing problems and acting in uncertain situations. The follow me model addresses the idea that the coach-student relationship consists of telling and listening, and demonstrating and imitating. Imitating is seen to be a creative act, in which the student must construct and appreciate the central features of the coach's demonstration, using them in turn as criteria to assess the quality of his or her own performances. The hall of mirrors model points to how the coach's performance, in supervising the student, is exemplary of the craft that the student is attempting to acquire.

Schön's three models of a reflective practicum are useful beginning points for conceptualizing the interaction between supervisory teachers and student teachers in practicum. This proposed research study is intended to explicate these ideas in a science teaching context.

Statement of Problem and Research Questions

The research problem of the proposed study is to conceptualize and investigate empirically the elements of a reflective practicum in constructivist science teaching. The first research question is analytic in character:

1. What does it mean to think "reflectively" about science teaching?

The second and third research questions are empirical in character; they will entail deriving the elements of a reflective practicum in constructivist science teaching from the supervisory practice of expert science teachers:

2. What are the elements of a reflective practicum in a constructivist science teaching approach?
    - 2a. How does the supervisory teacher conceptualize a reflective practicum?
    - 2b. How does the student teacher conceptualize the practicum experiences?
3. What are the criteria for detecting the elements of a reflective practicum in constructivist science teaching?

Preliminary Analysis

The analysis that follows is focussed on two discussions that took place between a student teacher, Barry, and his supervisory teacher, Mr. Kelly, during the first two weeks of Barry's second practice teaching assignment. (The names have been changed to preserve the anonymity of the student teacher and the supervisory teacher.) Mr. Kelly was selected for this study from a research group at the University of British Columbia that has been investigating students' intuitions and science instruction. In addition to being a well known and highly respected teacher in his school district, Mr. Kelly has used a constructivist perspective as a framework for guiding and interpreting his own science teaching, and he is familiar with the theoretical formulation of reflective practice as put forth by Schön (1983).

The supervisory dialogue is analysed for recurring patterns that can be seen in the discussion. A pattern of thinking about classroom phenomena from pupil's perspectives is identified in the dialogue, the conceptualization of which is aided by developing the notion of intellectual empathy for science pupils. I argue that in order to conceptualize what we might call a reflective practicum in science teaching, we need to explore the notion of intellectual empathy further, in terms of what it takes to evoke and detect in a student teacher intellectual empathy for pupils, as well as what it means when a supervisory teacher displays intellectual empathy for a student teacher.

Supervisory discussions between Barry and Mr. Kelly were audio-recorded and transcribed for analysis. Excerpts of two discussions are presented here to illustrate preliminary analysis of the dialogue.

A striking feature of the supervisory dialogue involves Mr. Kelly and Barry reflecting on classroom events from pupils' perspectives. Mr. Kelly repeatedly constructs plausible pupil interpretations of Barry's instructions, demonstrations, questions, etcetera. Two excerpts are presented to illustrate the pattern of Mr. Kelly introducing "pupil frames" to Barry. Both cases deal with a physics class in which Barry was teaching about ways of graphically representing motion.

The first excerpt deals with a question that Barry gave requiring pupils to draw a "line-of-best-fit" on a distance-time graph in order to solve for average speed of a moving body. Mr. Kelly recognized that at least one student, Beth, misinterpreted Barry's instruction to draw a line on the graph such that "half the points are on one side of the line, and half are on the other":

(K = Mr. Kelly, B = Barry)

K: Okay, that's something to think about. Sometimes its
useful to exploit a wrong answer. For example, the
[average speed] question . . . one of the answers
that I expected some people might give would be 24
rather than 21. And what they do is they just use
the "m" part in the y=mx+b . . . they get the slope
a bit wrong because they put it like . . . Beth over
there . . . what she was doing . . . she had an
interesting solution. You see, she said, "Well, you
told her to form half of the points on one side and
half on the other." Well, what she did was to join
the origin to the middle point.

B: Oh, I see.

K: Then above that point, all of them were on one side
and below that point all of them were on the other
side. So it satisfied the conditions that half were
on one side and half were on the other, but they
were not randomized.

B: Yeah.

K: So she had misunderstood. But do you see what goes
through kids' minds? Well then what you do, of
course, then you'll get 24 rather than 21.

B: Oh right.

K: And something to be . . . when you have to think
about evaluation, there's the notion of a carried
error. For example, if she makes a mistake there
and then she gets 24 because she made a mistake
before . . . but did everything else from that
point, how do you mark that?

B: It's just really the one error really.

K: Well you have to think about that. It's a
difficult . . . I don't think you can mark it all
wrong, but you have to conclude yourself how you're
going to sort that out. Uh, the other thing that
. . . I mean if the wrong answer doesn't come out
. . . like 24 . . . you see some kids think that you
work out slope by just dividing the "y" by the "x"
. . . and what they're assuming is that it goes
through the origin and that there is another point
there which is zero-zero.

B: Actually, that's a good point.

K: But you can do that because the "y" is really a
"delta y" and the "x" is really a "delta x" because
you have chosen another point, the origin zero-zero,
45 but you have just not bothered to talk about it.

Intellectual Empathy

The essence of Mr. Kelly's critique is summed up by his question at line 20, "But do you see what goes through kids' minds?" The excerpt illustrates how "what goes through kids' minds" is bound to the particular content at hand--in this case, finding the slope of a line-of-best-fit. Given the content-dependency of pupil perspectives and possible misunderstandings, Mr. Kelly draws extensively from a rich repertoire in making sense of the situation from Beth's position. He has vast knowledge of content and experience with pupils' misinterpretations of content. Further, it was Mr. Kelly who observed Beth working on the problem at her desk, and who had the time before hand to think about her interpretation of Barry's instructions. But what interests this investigator is the way in which pupil perspectives are introduced to Barry; the general pattern of examining classroom events from pupil perspectives seems to be well-established.

The next excerpt comes from the discussion that occurred on the following day. Again, the focus is on a pupil's misinterpretation of a distance-time graph. In this case, Mr. Kelly begins by drawing Barry's attention to the misinterpretation, after which he invites Barry to explain it:

K: There was another point at which one student looked at
the rising line on the distance-time graph and said,
"Oh, he's accelerating." Why do you think he said
that?

5 B: (10 second pause) Was that Mark who said that?

K: I'm not sure if he did . . . I thought it was
somebody over in this corner.

B: They would . . . I guess somehow the idea of
constant speed they would be thinking in terms of
10 a constant straight line. So not being on a slant
must be doing something other than . . . no, maybe
they don't think in those terms. I'm not sure.

K: One of the things that is a standard problem for
kids is confusing a distance-time and speed-time
15 graph.

B: Uhmm uhmm.

K: I wonder if this student was suddenly thinking that
because the line was rising that the speed was
increasing. And suddenly in his mind, he was
20 interpreting the vertical axis to refer to speed.
You see now, the reverse will happen. If you're on
a speed time graph, they'll think, "Oh, the speed is
changing."

B: If he'd . . . now, if he's thought that far ahead
25 . . . I can see a confusion. But we haven't even
talked about acceleration.

K: But he used the word.

B: Yeah.

K: Well, I think one of the things that might have been
30 done is to say, "Yes, this is a straight line . . .
yes, something is increasing, but distance is
increasing and we call that speed. Later on, we're
going to look at how you represent acceleration."

B: Yeah.

35 K: And it's easy to get the two confused. Uh . . . you
recapitulated, which was good, you said, "Well, what
we've covered today was this, this, this and this."
I like that. That kind of summarized it at the end.

It is impossible to know what was going through Barry's head during this interchange. His speech at lines 8 - 12 is interesting. Although he concedes his confusion about the way Mark could have been interpreting the graph, he does give the general explanation of the misinterpretation that Mr. Kelly later constructs. Barry does say, "somehow the idea of constant speed they [the pupils] would be thinking in terms of a constant straight line. So not being on a slant must be doing something other than . . ."

If we interpret Barry's use of "straight line" to mean a horizontal line, then it may be safe to say that he has already explained the pupil's misinterpretation in the way Mr. Kelly goes on to. This interpretation raises questions about how much of the analysis should be left to Barry. Surely, Barry's confidence in systematically analysing his teaching performance rests on his developing autonomy as a competent science teacher. Such autonomy, I would argue, is inextricably bound to the way in which Mr. Kelly recognizes and responds to Barry's reflections.

An alternate interpretation of this excerpt is that what we have here is good teaching on the part of Mr. Kelly. Putting aside questions about developing autonomy and how much of the analysis should be left to Barry, notice that Mr. Kelly delivers the input that is required by Barry to help make sense of a situation, which, at first, is perplexing. Mr. Kelly knows about the likelihood of students to misinterpret a distance-time graph as respresenting acceleration. As noted above, this is the kind of knowledge that comes with teaching experience. It is the kind of knowledge that we could not expect Barry to "discover" on his own before gaining the required experience; if left to be autonomous in a situation such as this, Barry could well "flounder." In my mind, the scenario captured by these alternative interpretations of the excerpt presents and intriguing dilemma faced by supervisory teachers: should the student teacher be allowed to develop autonomy at the risk of floundering? This point will be taken up later in the discussion of Schon's "coaching models."

Before proceeding here, it will be useful to review the notion of intellectual empathy for science pupils. This notion has been derived from a preliminary analysis of Mr. Kelly and Barry's supervisory dialogue; it is manifest in an explicit attempt to "see" classroom phenomena from pupils' points of view. Thus far, I have shown how in the supervisory dialogue pupil interpretations are introduced in a rather didactic fashion, much of the intellectual work being done by Mr. Kelly. The next excerpt illustrates a instance where Barry initiates and completes the framing of a plausible pupil interpretation. The discussion is focussed on another physics class, in which Barry introduced a model to explain electrostatic induction:

K: One of the things you can . . . one of the ways to
answer a question . . . if you say, "What does a
water molecule look like?" and you say it's H-O-H
. . . if it was in line here, would it behave any
differently than it does? So you see . . . an "if,
then" sequence. Say, "What are the implications of
your explanation?"

B: There is a question I can anticipate coming out of
that. We've been talking about these sticks and
objects . . . all kinds of . . . the electrons moving
around and they might simply say, "Okay, so your
molecule is a straight line, but why don't the
electrons all zip over to one side anyway?" Wouldn't
those little molecules act like little acetate strips
or little . . .

K: All right, that's . . . that's . . . you
mentioned . . .

B: I don't know if they'll ask that.

K: You're saying that the molecules move?

B: No, I'm saying that a kid might say that . . .
here's your molecule . . . why don't the electrons
all sort of head over to that direction a little
bit?

K: Oh, so they . . .

B: But I don't know if they'll ask that, but . . .

K: So what you're saying is that essentially the atoms
are rearranged because of the field they're in . . .
is that what you mean?

B: They might say that . . . they won't say that the
atoms . . . yes. Yes, the atom itself. The
electrons within the molecule might rearrange leaving
this little unit. You know, it's as easy for them
to think of that explanation as it is for them to

think of that one.

K: Yeah. I would say at that point, "That's a terrific explanation. That's a very creative . . . and if you were a scientist and didn't know what the water molecule looked like, that's a perfectly legitimate model." And then you say, "Well, do we have any other information?" For example, I would say that there might be things that you could explain with this vee shape that you couldn't explain with the other.

B: Snow crystals and . . .

K: Snow crystals. "Can you explain snow crystals using your model?" And you say, "Well, you might adapt it again." But that's really good teaching I think. When you take a model that the kid has suggested such as your reorganization of the electrons . . . and say, "Okay, that's a good model. You've come up with something that explains this particular instance. Are there any . . . let's test it." And push it and push it. You don't say, "It's not right."

The above excerpt supports the claim that Barry seems to be developing the disposition for interpreting classroom events from the perspectives of pupils. The discussion carries on with some very interesting dialogue about the nature of scientific models. Notice, though, that while Barry seems to understand the general strategy of negotiating with students about acceptable explanations, he does raise a dilemma concerning his knowledge of content, and his ability to respond in appropriate ways to students' ideas. The problem he faces, of course, may only be resolved with more teaching experience:

B: Yeah, I realize that you don't say it's not right. I have a problem with just having the right things at the fore-front of my head to deal with those kind of questions. I don't think they would be there. I don't know how I would deal with . . . well, I'd kind of get flustered, I think, 'cause I wouldn't have it right there . . . the right explanation for the Grade 10. I would have it there if somebody else explained to me why that model is wrong . . . I'd understand their explanation, but I don't know if I'm far enough along to . . .

K: Well, how do you see your role with respect to a question like that? Do you feel that you always have to know the answer?

B: Uhmm, I feel that it's important. It's not that I always have to know the answer, I think that if you do know the answer you're a much better teacher . . . if you can drag that up. So that you can collect all the things that you do know and you can focus them on the issue. That's the point I'm making . . . is that a lot of those questions do come up . . . and I know a lot of stuff, but it's not organized to flow into the answer.

The problem that Barry raises about not having content organized in such a way to "flow into" responses to student questions is interesting in its own right. Mr. Kelly may ease the tension inherent in Barry's dilemma when he reflects on his own experience in recognizing and responding to the kind of pupil questions and interpretations to which Barry refers:

K: Yes. Well I would think at that point that you don't necessarily have to hold up the whole class and say, "We can't go on until we solve this problem." Uh, I find myself saying . . . when I come across that . . . there are times when a kid asks and doesn't really realize himself how good of a question it really is. There are times when I recognize it as being a good question. Say, "Well, what you're really getting at is this underlying problem . . . and I don't really know that but I'll try to find out and I'll get back to it." Sometimes I miss it. You know, you're just not going to pick up on all of them. But if somebody came up with that sophisticated model that you're describing . . .

At this point it is worth mentioning that I discussed the notion of intellectual empathy with Mr. Kelly, and I explained that I thought there was sufficient evidence in the dialogue to indicate that Barry was beginning to acquire the disposition to examine classroom phenomena from pupils' perspectives. Mr. Kelly agreed that Barry was showing signs of being able to empathize with pupils intellectually, but went on to tell me that Barry was experiencing difficulty relating to pupils on social grounds. Mr. Kelly's report was echoed by another supervising teacher with whom Barry had been working, who contrasted Barry's "content orientation" with another student teacher's "pupil orientation."

Mr. Kelly explained how he made an explicit attempt to model the kind of behaviour toward pupils that he felt was lacking in Barry's teaching. At the beginning of one class, Mr. Kelly stood at the door casually talking with pupils as they entered the room. He spoke loudly enough so that Barry could hear the interactions and note the kind of information Mr. Kelly was gathering about the pupils. Later, during the discussion of the lesson, Mr. Kelly described what he was attempting to do and why he was attempting to do it:

K: Okay, there were a couple of things about the physics. They're mostly fairly small. One of the things . . . is that when you circulate with the kids after you've taught your lesson . . . or at the beginning of the period . . . uh, I think it helps to try to get to know the kids. What I mean is . . . I'll give you some examples. Nellie . . . who's sitting right a front . . . she's an interesting case. She's an art student and . . . just talking to her today I found out that she wants to go into the military. She's very interested in physics and she said that she has made a decision that for her purposes physics is going to be the most interesting or useful of the science courses . . . for that purpose. Now that makes her interesting because she's involved in the militia and that gives her a whole background of practical experience exposure to ballistics and whatever . . .

B: So examples you can pull . . .

K: If you know that you can call on that. Now, let's see . . . one thing that was happening today . . . what's that girl in the corner . . . Carol . . .

B: Carol, yeah.

K: She is a very proud lady at the moment because her sister has just had a baby. She's very turned on . . . she brought a picture, she was showing it to her friends.

B: Yeah.

K: Now, if you know that personal side to it, you will make a special contact if you just touch base on that.

B: Uhmm uhmm.

K: Don came in today. He was at outdoor school. If you know that there might be a time when you can tap into that as an example for a question or something.

B: Yeah, that's . . .

K: Now, I'm just trying to . . . these two boys here . . . Stan and . . .

B: Stan and Fred . . .

K: . . . and Fred . . . they're basketball players.

B: Yeah.

K: Every time they come to class they put on the tie? That's the sign that they have a basketball game that day.

B: Oh, I see.

K: And they have a game that they're thinking of today. I think it's against . . . who is it against? I don't know who it's against, but you could use . . . see, ballistics and basketball go very good together.

B: Oh yeah.

K: Now, you're not going to do ballistics actually but you can use examples . . . you could ask them to bring in a basketball . . . you could ask them to describe what it feels like when a ball is under various conditions.

B: Well, the example with the ticker tape . . . if you were bouncing a ball at a steady rate, how far is it between . . . where it hits the floor if you're going fast or going slow or standing in one place?

K: 'Beautiful example. As a matter of fact that is such a good example you could almost have a kid come up and demonstrate that.

B: Yeah, that would have been ideal. Well, I could still fit it in.

K: But do you see my point . . . that just tapping into

some of these special experiences of the kids will
build up a relationship for you . . . but it will
also allow you to build on those four examples. I
mean that basketball example you just described would
70 have been fantastic.

Barry is rightly commended by Mr. Kelly for the "ticker-tape-basketball" example of "tapping into some of these special experiences of the kids." Further, I think that Mr. Kelly should be commended for his demonstration and description of a feature that he apparently regards as being central to the craft of teaching, albeit difficult to describe. Let us return to the discussion here, noticing both the rather awkward description of this feature that Mr. Kelly delivers, as well as the evidence that Barry fully understands it (cf. lines 5, 15, 33, 38):

B: I find . . . I have tutored people and things . . .
and there I do that. I've often used that. In fact
I often thought of starting to explain something was
that some how what you've been saying and their
5 understanding has become [separated] . . . it's a
matter of going back until you find a place where
they're stuck together and then taking them along.
What I find difficult with the class, though, is
. . . my memorization of names isn't great. But I
10 can work on that. But I just get a bit floored by
all the other things.

K: There's so many things happening.

B: That's what I find . . . all these examples . . . if
I was talking to Stan and I knew he was a basketball
15 player, then that is how I would go about it . . .
because I have done that sort of stuff. But as a
class I find it . . . and I find all that spark, and
that is the spark . . . that's lost.

K: I think that we might have the organizational thing
20 in gear well enough that you can begin to go on to
something like that. Why don't you try it with your
Science 10 tomorrow? Talk to them . . . you know,
you don't have to pick out . . . I don't know how
exactly you go about doing it . . . I mean, the human
25 being in conversation . . . you know, I . . . just
talking to these kids I found out about Nellie when
she came in. I don't remember exactly the context
. . . we were just talking and then she started
telling me about why she was taking physics. And
30 then she was telling me this . . . uh, Carol, she
had a picture in front of her, and these kids
here . . .

B: Well Nellie made a comment about . . . "Well, I'm
just an art student . . ." And I thought well, I
35 want to do something with that comment. And then
there were so many other things to do.

K: Well, put it on the back burner.

B: Yeah. Yeah, I can see that there's tremendous power
in that.

Mr. Kelly's approach to supervision can be cast in a variety of ways. There are times at which he adopts a follow me model, as illustrated in the passage above. At other times, Mr. Kelly and Barry share in joint experimentation, an example of which would be the dialogue concerning electrostatic induction. Of course, these models require sorting out, in terms of their use in understanding various approaches to supervision, as well as their consequences for the student teacher. Before proceeding with that task, though, it will be well to examine one more excerpt from the discussion on the second day.

What makes this next passage interesting is that it occurred on the day after the discussion about "tapping in to some of these special experiences of the kids." Barry had just taught a lesson in which he showed a class of 32 pupils a demonstration of electrostatic induction using a van de graaf generator. He wasn't happy with the lesson for several reasons, one of which was that few pupils were able to see the demonstration well enough to become involved in the lesson. Mr. Kelly asked Barry to think about the way he had been grouping pupils; perhaps the class could be split in half, each responsible for its own activity:

K: Do you think it would have been possible to get one
going in one group and the other going in the other
group?

B: Yeah, except that one's more exciting than the
5 other.

K: Which is more exciting?

B: Well, that van de graaf generator's intrinsically
more exciting. I don't know . . . I guess I could
have probably taken somebody like Allan, actually,
10 who's done the electronics and said, "Here . . .
show half of them how to do it." That would have
worked. That might have worked well.

K: Do you think that the fact that he knows
electronics is indicating that he's competent in
15 electrostatics?

B: Uh, not necessarily, but he's very competent anyway.
I think, in fact, there were a couple of people that
had the induction idea no problem. And I think
. . . I suppose there's always the risk they might
20 have explained it all wrong to somebody.

K: I think you can use students to teach each other.

B: Oh, yeah.

K: What are the objectives of the induction with the
record? You're trying to teach them the four steps?
25 Did that come out?

At the risk of "reading into the data," I think that Barry shows at lines 5 - 10 that he is able to do precisely the sort of thing Mr. Kelly meant by "tapping in to" pupils' experiences. What we don't see in the dialogue, though, is Mr. Kelly's recognition and approval of Barry's acknowledgement of Allan's personal experience with electronics. Nevertheless, there is evidence that Mr. Kelly has been successful in modelling the pattern of "tapping pupils' experiences," even though Barry may be doing so out of concern for his ability to handle the content he is teaching.

Conclusion

Preliminary analysis of the supervisory dialogue has raised important questions regarding the nature of a reflective practicum in science teaching. In summary, a pattern of reflecting on classroom events from the perspectives of pupils was identified in the dialogue. The notion of intellectual empathy has been developed and discussed as a means of describing the pattern, and excerpts from two supervisory discussions have been presented to illustrate cases of intellectual empathy in the discourse of both Mr. Kelly and Barry. While the analysis has shown that Barry may be developing the disposition to examine classroom events from pupils' perspectives, there is reason to suspect that he does so out of a general concern for his own mastery of science content and his survival as a teacher. Nevertheless, Barry does display a tendency to analyse content and teaching strategies from pupils' points of view.

Mr. Kelly's approach to supervision seems to fit most closely with the follow me model of coaching (Schön, 1987), although there are times when a joint experimentation model is evident. The analysis of the coaching approach has led to important questions concerning what the joint experimentation and hall of mirrors models would look like in practice, the conditions around which they might evolve, as well as the different demands they place on the coach and the student in different contexts. Further work is required to sharpen the distinction among these coaching models, if indeed they are distinct, to illustrate them in practice, and to show their consequences for student teachers.

Limitations of the Study

As this study proposes to conceptualize a so-called reflective practicum in science teaching, its major limitations are in the theoretical underpinnings upon which data collection and analysis are based. Schön's views about professional education and reflection-in/on-action, along with a constructivist perspective of teaching and learning, comprise but one way of viewing the matter of educating science teachers. While the conceptual orientation of this study will offer certain insights about the thinking of competent science teachers as well as the development of their thinking about practice, so it will truncate events and hide other important understandings about practicum.

Other limitations are inherent in conducting research in a practicum setting. Practicum situations are typically fragile enough left alone; the risk associated with the student teaching role can be extremely high notwithstanding having to contend with a research project. Situational demands and conflicts that are placed on the student teachers involved in this proposed study must be monitored constantly, giving utmost consideration to the development of persons. This research study should not impede that development in any way. Indeed, the study is conceived to do just the opposite by examining the initiation a student teacher into a defensible way of thinking about teaching science.

Implications for Further Data Collection

Data presented in the preliminary analysis were limited to supervisory discussions held between a student teacher and his supervisory teacher. Discussions between the investigator and the supervisory teacher were held, but these were not audio-recorded for transcription and analysis. Three weeks after the end of the practicum, the student teacher was interviewed by the investigator, but the analysis of that discussion has not been presented here. Nor were any of the student teacher's lessons observed or recorded. Regular interviews with both the supervisory teachers and the student teachers, together with audio- or video-tapes (depending on the individuals and their situations) will be valuable contributions to the data base for this study, providing their collection is not too obtrusive.

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STUDENTS' UNDERSTANDING OF PARALLEL LINES: SOME IMPLICATIONS FOR TEACHING

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In our previous research (Mansfield, 1984; Mansfield and Happs, 1987), we have identified several misconceptions about parallel lines that students commonly have. For example, many students believe that parallel lines do not need to be straight, whereas in school geometry lessons they are presented as straight. Many students also believe that parallel segments need to be aligned. Some students believe that the presence or absence of arrows or dots on the ends of lines affects whether or not the lines are parallel. These misconceptions are common in each of the groups of students we have interviewed, both in the US and in Australia. We have found them amongst students who have received no formal instruction on parallel lines and amongst students who have just received instruction.

In this study, we tried to change the ideas about parallel lines held by a class of students, having in mind conceptions that they were likely to bring to our lessons. We monitored one group of students within the class in order to document the impact of our teaching strategy.

Procedure

We worked with an unstreamed class of twenty-nine 13-year-old students from a Western Australian high school. At the time of the study, the class had not been taught the topic of parallel lines.

A group of six students (three boys and three girls) was selected at random to be monitored during the teaching. They were interviewed individually prior to the lessons, immediately following the lessons, and one month after the lessons finished. The monitoring and interviewing were carried out by the second author.

In the initial interview, the students were asked to say what they understood by the term "parallel lines." The students were then shown ten items depicting examples and non-examples of parallel lines (see items 1-10 in Appendix A). They were asked to say whether each was parallel or not and to give reasons for their answers.

A similar procedure was followed in the interviews immediately after the lessons and one month later. In both these interviews, fourteen items were shown to the students in addition to the original ten (see items 11-24 in Appendix B).

The teaching strategy was designed to utilize the students' misconceptions about parallel lines, to make the students aware of different views within the class, to present them with the common mathematical view, and to enable the students to modify their existing views.

The class was taught for four 40-minute lessons by the first author. During the lessons, the students worked in groups. The six students who were being monitored formed one group. The second author sat with this group and documented their interactions with each other and with the teaching materials and information given by the first author.

The lessons included the following episodes.

1. Each group was provided with copies of the ten items used in the initial interviews (see Appendix A). They were asked to make a group decision about whether or not each item represented parallel lines. These decisions were discussed, along with the students' definitions of parallel lines.

2. The class was shown how mathematicians would categorize the items and was asked to attempt to identify the mathematicians' reasons.

3. The students were shown several examples of skew lines in the classroom and discussed the difference between parallel lines and skew lines. The word "co-planar" was introduced.

4. The students were shown how a transversal through parallel lines would lead to corresponding angles being equal.

5. The students were given the opportunity to check lines for parallelism by simple techniques for measuring angles and distances between lines.

6. The distinction between "line segment" and "line" was made and students were shown how to check the parallelism of non-aligned line segments by the parallelism of their extensions.

7. Finally, the students were provided with an activity that allowed review and application of some of the ideas discussed during the lessons.

The Students' Interview Responses

In this section, we present a summary of the responses of the monitored students in their three interviews. Table 1 shows the characteristics of parallel lines mentioned by the students in their definitions.

As table 1 suggests, Teresa was unfamiliar with parallel lines prior to the teaching. Karen and Enore used descriptions whose meaning was unclear. By the second interview, all the students were able to give quite clear definitions. In her first interview, Holly suggested that parallel segments must be aligned, a property that she also referred to in her post-teaching interview.

Table 1

Characteristics of Parallel Lines Named in Definitions by Students

Student	Interview 1 (pre-teaching)	Interview 2 (post-teaching)	Interview 3 (one month post-teaching)
Holly	straight equidistant opposite each other	straight equidistant opposite each other	straight equidistant
Karen	nonintersecting "straight to each other"	straight nonintersecting infinite length	straight equidistant
Teresa	unsure of meaning, possibly straight	straight equidistant nonintersecting	straight equidistant nonintersecting
Ben	equidistant	equidistant straight	infinite nonintersecting equidistant straight co-planar
Martin	nonintersecting infinite straight	nonintersecting infinite straight equidistant	nonintersecting infinite straight equidistant co-planar
Enore	straight "horizontal to to each other"	equidistant nonintersecting	equidistant nonintersecting

In the first two interviews, no student referred to the requirement that parallel lines be co-planar. However, both Ben and Martin referred to this requirement in their third interview. This suggests that these two students had in the month after the teaching constructed a view of parallel lines that was mathematically sophisticated and resembled that aimed for in the lessons.

Even when the students gave criteria that were correct, their responses to the items suggested that these criteria were not always applied in judgments about parallelism. Table 2 shows the number of correct responses made by the students in each of the interviews and identifies the items that they answered incorrectly. As Table 2 shows, the students achieved a good level of correct responses in the post-teaching interview that was sustained over the month to the final interview.

Some individual responses are worth noting. In her first interview, Holly defined parallel lines as straight but changed her mind when shown the items with curved lines. Similarly, Ben and Karen also decided that parallel lines need not be straight. In their post-teaching interview, all three students defined parallel lines as straight and responded to the items consistently with this view. It seems that prior to instruction, even when students defined parallel lines as straight, their conception of parallel lines was so insecure that plausible curved nonexamples led the students to change their definitions to accommodate the nonexamples.

In her first interview, Holly thought that line segments must be aligned. Item 11 (see Appendix B) showed two line segments that were not aligned. In both her second and third interview, Holly said that the segments in this item were not parallel. This item was also answered incorrectly by Karen. The alignment of segments was also of concern to Teresa who said in her first interview that the segments in item 3 (see Appendix A) were not parallel because they were not "straight over each other." In both her second and third interviews, Teresa judged the segments in item 17 (see Appendix B) to be not parallel because "they'll never be underneath each other." The presence of dots on the ends of the segments in item 17 were significant for Teresa and meant that these segments could never be aligned. It seems that alignment was a significant factor for some of the students in deciding whether or not segments were parallel and this remained a barrier to understanding after the teaching.

Table 2

Number of Correct Responses by Students to Items in the Interviews

	Interview 1 (pre-teaching)	Interview 2 (post teaching)		Interview 3 (one month post-teaching)	
Student	10 items	10 items	14 items	10 items	14 items
Holly	5 [a](2,4,6,7,8)	10	13 (11)	10	13 (11)
Karen	4 (2,4,6,7,8,9)	10	12 (11,18)	10	13 (11)
Teresa	8 (2,3)	10	13 (17)	10	13 (17)
Ben	4 (3,4,6,7,8,9)	10	13	10	14
Martin	9 (9)	9 (9)	13 (11)	9 (2)	13 (18)
Enore	9 (2)	8 (1,3)	11 (11,14,17)	8 (1,3)	13 (14)

[a] Numbers in parentheses identify which items the students answered incorrectly.

In their first interviews, both Ben and Martin gave interesting responses to item 9 (see Appendix A) in which the curves intersect. Both students perceived this item as possibly three-dimensional with the curves being parallel if viewed from above. These responses suggest that even where a figure shows intersections clearly, students may be interpreting the figure differently from the way expected by the teacher.

Finally, with several of the items, the students made incorrect intuitive judgments on the basis of a quick visual appraisal and did not see a need to check the parallelism of the lines in some way. Even when the students used a ruler, there was some difficulty in using it correctly. For example, Enore was unable to use a ruler correctly throughout the interview and so judged some items incorrectly. Holly was the only student who did not make at least one incorrect intuitive judgement or use a ruler incorrectly.

From the results described above, it is clear that our teaching program was successful in changing the students' ideas about parallel lines, particularly with respect to straightness. This change was sustained for a month. It is also clear that there were still barriers to the students' understanding of parallel lines. Alignment was still a difficulty as was using a ruler to measure appropriately.

Interactions during the teaching

In this section, we highlight some of the reasons for the students' views of parallel lines, how they arrived at those views, and some of the difficulties that emerged during the teaching.

Past learning experiences

Some specific past learning experiences were seen as contributing to the generation of misconceptions about parallel

lines. In their discussion of the first ten items (teaching episode 1), Holly, Karen and Ben thought that item 6 (concentric circles) represented parallel lines. Ben argued his case in terms of what one teacher had told him about lines of latitude being parallel. Lines of latitude are parallel, but in school geometry parallel lines are straight. This is an example of the correct use of a term in one context leading to the assumption of properties of the concept that do not apply in other contexts.

In another situation, an inappropriate example of parallel lines met previously by students proved confusing, as the following lesson extract shows. The teacher (HM) had built up with the students the definition of parallel lines and was moving toward the inclusion of "straight" as an important criterion.

HM: ".... Is there anything else that we really should add in to the definition to make it complete?"

LIAM: "Umm .... straight."
(from another group)

HM: "Straight lines. OK, we really need to put in that they're straight lines."

TERESA: "They don't have to be straight."

SEVERAL CLASS MEMBERS
IN UNISON: "Yes they do."

TERESA: "Because railway lines are parallel and they're not always straight are they?"

HM: (indistinct)

TERESA: "That's what teachers say."

Difficulties with measuring angles

The teacher (HM) discussed with the class how a mathematician would judge lines for parallelism and asked the students to draw a pair of parallel lines using opposite edges of their rulers. The students then drew a transversal through the parallel lines and used tracing paper to find as many equal angles as possible. The teacher led the class to the conclusion that corresponding angles are equal.

By way of comparison the class was asked to draw lines that were not parallel so that they could discover that corresponding angles are not equal when nonparallel lines are intersected by a transversal. Some difficulty was met here as some students drew lines that were almost parallel and the small differences in angle sizes could not be detected by the students.

The class was then asked to draw transversals through the first ten items used in the interviws (see Appendix A) and to use tracing paper to compare corresponding angles. Incorrect measurement of angles led to some difficulty in this task so that lines that were not parallel were thought to be parallel. For example, Karen measured incorrectly the corresponding angles in item 4 and concluded that the curves in this item were parallel. Some conflict emerged between Karen's incorrect observations and what she recalled as being the mathematical view of item 4.

INTERVIEWER (JH): "So are they (lines in item 4) parallel?"

KAREN: "They're not parallel."

JH: "They're not parallel?

KAREN: "They are ... but a mathematician would say not."

JH: "Number 4 was not classed parallel by a mathematician but you find the angles are the same and they are parallel?"

KAREN: "Yes."

Clear problems emerged when the criterion of corresponding angles was used on pairs of lines that were not straight. For example, when students drew a vertical transversal through the curves in item 4, they found the corresponding angles to be equal. This seemed to reinforce the initial views held by some students that parallel lines need not be straight.

Difficulties with measuring distances

In an attempt to overcome difficulties of measuring with rulers, the teacher showed the class how to use a rectangular card to measure between lines and for some students this technique proved successful. Teresa, however, had problems with using the card and had to be shown by others in the group, as the following extract shows.

INTERVIEWER(JH): "Well how can you use that (the card) to measure the distance between the lines (in item 3)?"

TERESA: "You measure the card and you put marks on the card ... just like a ruler (demonstrates by placing graduated pencil marks on the card)."

JH: (After watching Teresa "measure" both ends of the lines). "Then you move it along ... right along the lines to see if it changes?"

TERESA: (nods) "No - it's not parallel."

JH: "It's not parallel ... why was that?"

TERESA: " 'Cos I started down there and I went up to there and it doesn't fit in."

JH: "OK. So they're not the same distance apart?"

TERESA: "No."

HOLLY and KAREN: (in unison) "They are."

Karen then demonstrated the measurement using her piece of card and this peer teaching episode appeard to convince Teresa that she had measured incorrectly with her card.

Conclusions

The teaching strategy we devised for the topic of parallel lines was partly successful with the students we monitored. We were successful in increasing the number of correct responses to the items we used. The students who thought initially that curves might be parallel were convinced that they are not. Nevertheless, some real-life situations such as railway lines still posed difficulties and were not necessarily seen as nonexamples of the definition of parallel lines. We may have succeeded in giving some students a fairly clear view of parallel lines for use in school while leaving intact their earlier view for use in situations outside the mathematics classroom. These students can presumably choose whether or not to use their newly-acquired conceptions in judging situations such as railway lines.

While we were successful in convincing the students that parallel lines are straight, we found that there still existed at the end of the teaching some conceptual and mechanical barriers to a complete mathematical view. Some of the students were still unsure of the parallelism of nonaligned segments and the distinction between lines and segments caused some difficulty. A further difficulty was the students' inability to use measuring instruments appropriately. This was coupled with a preference for judging parallelism merely on visual appearance even when measuring instruments were provided and their use suggested. Apparently these students did not distinguish clearly between proof on the one hand and personal conviction on the other.

Our final interview with these students was carried out one month after the teaching program. In that month, the students maintained the gain in knowledge of the concept that they had acquired and in two cases improved it by recognition of the necessity of co-planarity as a criterion. We intend to interview these students again in twelve months' time to see whether the conceptual changes are long-term. Of course, we cannot control the school or other experiences related to parallel lines that these students will have.

The difficulties in measuring that we found were surprising. We need to investigate the measuring difficulties of students in situations both similar to and different from this. We believe that we need to build into our teaching strategy some activities to make students aware of ways of measuring accurately and, most important, the need to do so.

While our teaching program was not completely successful, it did achieve some pleasing outcomes. We believe that its success was based on the fact that we did not try to present a mathematical view of parallel lines as a finished, complete product. We started from our knowledge of the students' existing viewpoints and led the students to recognise the diversity of views within the class. We established a conflict between the views of some students and the common mathematical view and tried to provide the students with opportunities to explore situations that would show their existing views to be inappropriate.

Not surprisingly, the students' familiarity with the term "parallel" in contexts other than school geometry lessons hindered our efforts with some students. We remain convinced, though, that recognition of students' existing conceptual frameworks and the use of them in devising teaching strategies are critical to good teaching.

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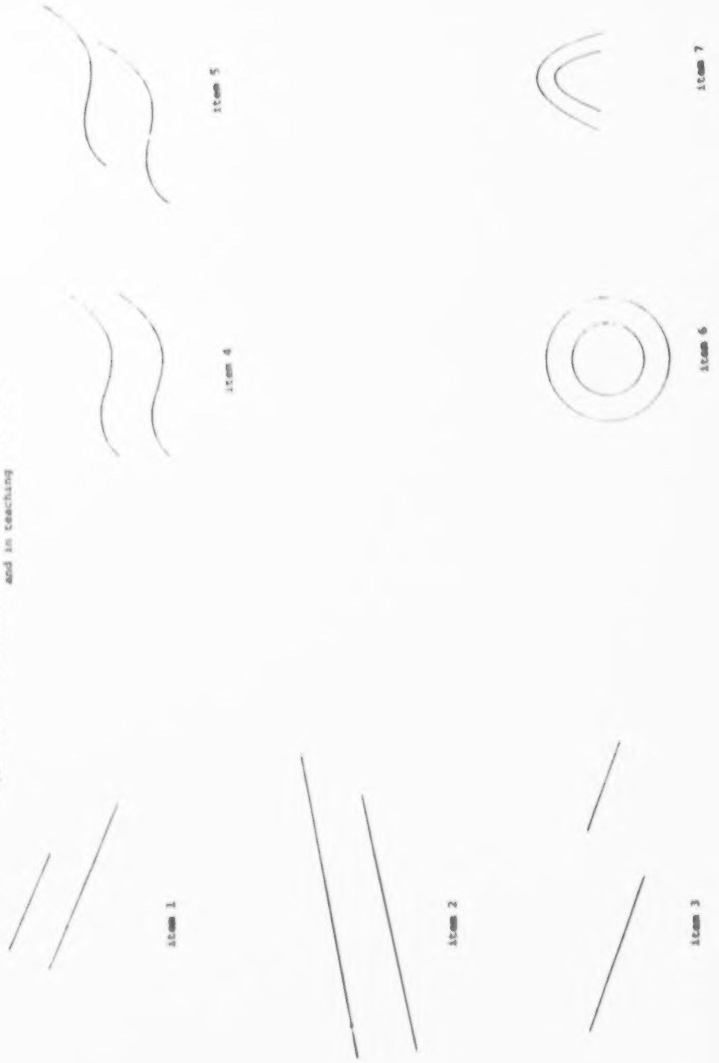
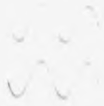
Mansfield, H. M., & Happs, J. C. (1987). Students' ideas about parallel lines. Unpublished paper.

Appendix A: Ten items used in interviews 1, 2 and 3 and in teaching



Appendix B: Fourteen items used in interviews 2 and 3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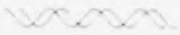
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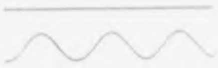
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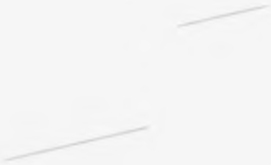
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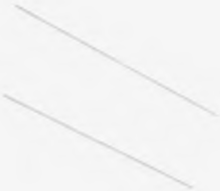
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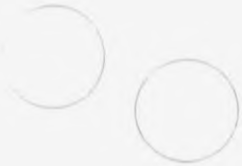
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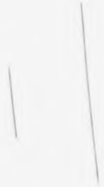
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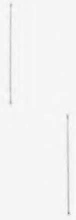
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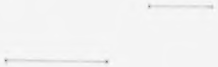
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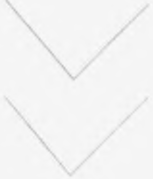
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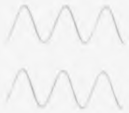
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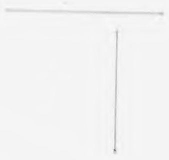
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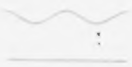
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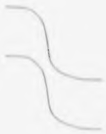

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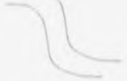

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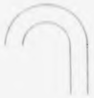

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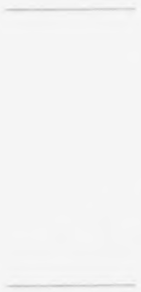

item 24

SECONDARY SCHOOL STUDENTS' LOCUS OF CONTROL AND CONCEPTUAL KNOWLEDGE RELATING TO HEALTH AND FITNESS

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INTRODUCTION

Health is an essential component of a happy life. With improved medical practices the probability of surviving youthful diseases and living many years beyond retirement is growing stronger. To enjoy this longer, healthier life, people must learn to survive the enticements of junk food, the hazards of excessive drinking and smoking, as well as a myriad of other threats to their well-being. Besides the individual benefits to be gained by proper health and fitness practices there are numerous societal benefits. The costs of medical insurance and hospital services have increased alarmingly in the last few years. Any inroads into this growing problem would pay handsomely for the individual, the employer, the insurer and the government. Indeed the health insurance agencies have recognized the calamity that looms ahead if health habits are not changed. Many companies are actively encouraging enrollment in new health maintenance organizations that emphasize wellness rather than sickness. Subsequently, those companies design health coverage accordingly since they hope to entice subscribers into utilizing programs that promote health and fitness rather than paying the costs that stem from their clients neglect of their bodies' needs.

In her review of the health education/science education overlap, Garrard (1986) writes that science teachers are involved in health education in two ways: Through the incorporation of health related topics within general science and biology curricula and through the teaching of health education as a separate subject. Most school curricula include the study of health, incorporating the topic in both science and physical education programs (Pollack and Hamburg, 1985). In Western Australia, health education is a formal part of the school curriculum and is taught by health education teachers as a separate subject. However, a survey by Laird (cited in Garrard, 1986) showed that 41% of Australian secondary health education teachers come from a science teaching background. The Health Education Syllabus for Years K-10 (Education Department of Western Australia, 1986) involves a spiral curriculum which addresses aspects of food groups, diet, eating habits, exercise, nutrition, fitness, and life-style related diseases in greater detail as students progress through grades 4-10. As with all health education programs the aim is to establish habits that will be personally profitable (better personal health and physical fitness) and publicly less costly (fewer medical problems). Each year new health problems seem to appear, increasing the complexity of medical treatment. One hope for confronting this growing problem is to arm young people with the tools to keep themselves as healthy and fit as they know how. Yet, students often leave school without a clear understanding of many health concepts (Health Education Council 1982; Peers and Christie 1984; Skinner and Woodburn 1984; and Weinberg et al., 1984).

According to Garrard (1986), health education research can be differentiated into two broad but interacting categories: Descriptive/ explanatory research and interventionist research. The work described here falls into the first category and blends with a constructivist learning model (Pines and West, 1986). In examining theories of learning, Novak (1977) emphasized the need to identify students' conceptual knowledge and beliefs early in instruction, and then to use this information in choosing subsequent strategies and materials for student learning experiences. Research indicates that students often hold beliefs about science topics that are incongruent with accepted principles and theories. Strike and Posner (1982) and Williams (1981) suggest that learning is more likely to occur when instruction is centered on diagnosing and correcting misconceptions or improper preconceptions. In health education, there are few research studies that have used the constructivist model of learning. In a review of health education research, Rothman and Byrne (1981) stress the need for concerted efforts to provide a research base for decision making in health instruction. Brumby, Garrard and Auman (1985) report that while there is a paucity of misconception research in health education, some studies show students to hold a wide range of beliefs concerning health.

In investigating students' perceptions about control of their health, Wallston and Wallston (1978) reported that many concepts which students believed were important to their health and lifespan were also held to be beyond their personal control. Consequently, students need to see the relevance of learning about health and fitness and they need to accept a large measure of the responsibility for their personal well-being. Indeed, Maddock (1983) reports that students' attitudes toward health and their awareness of health issues are not highly correlated. Of equal concern is Kolbe°s (1985) findings that while students' knowledge, attitudes and skills concerning health are consistently improved through school health education programs, health behaviours are seldom influenced. Among likely factors influencing this lack of understanding of health concepts and principles is a sense of lack of control over this aspect of their lives. Indeed, students often see relevant others as responsible for much of their education, their recreation, and their growth (Newman, 1984). Students also tend to confuse the learning of knowledge in health education with a true understanding of the topic and how they should be personally involved in directing their own health programs (Veenker, 1985). Garrard (1986) suggests that 'healthy' health educators are those who can successfully integrate learning about health and fitness and learning to perform according to what they learn. Garrard also reports that assertiveness training is being added to health education by some teachers in the hopes of bridging the gap between knowledge and practice.

PROBLEM

In this study, an examination of the conceptual knowledge and locus of control of students in health education classes was undertaken in secondary schools in Western Australia to investigate the 'condition' of health education among grades 8 and 9 students (12-14 year olds). Specifically two questions were used to provide guidance for the study: What is the status of student knowledge regarding personal health and physical fitness education concepts? and, How do students view their locus of control over personal health and physical fitness related practices? An additional goal for this study was to commence the development of a diagnostic test that would help teachers of health education identify problem areas involving misconceptions about health and fitness. With this added knowledge about student learning, teachers may be able to choose strategies and activities which would enable their students to more effectively engage these problem areas? The improvement of this diagnostic test is on-going.

METHODS

Instrumentation

Data for this study were gathered using interviews and a variety of

pencil and paper measures.

Student conceptual knowledge was obtained initially from interviews with grades 8 and 9 students from two schools in Perth, Western Australia to identify preconceptions, misconceptions, and areas where knowledge about personal health and physical fitness was consistent or inconsistent with the concepts included in the Western Australian Health Education Syllabus (1986). Using semi-structured interviews, the researchers talked with groups of three or four students and student discussion was encouraged on the following questions: What does it mean to you to be healthy?; How would you go about finding out who was the fittest person in your grade?; Why do we want to control our weight?; What does it mean to you when someone says they are going on a diet? The interviews were tape-recorded and transcribed verbatim. The wide range of responses was tallied to identify the most common misunderstandings, preconceptions and misconceptions. These interviews served as the foundation for the creation of a 20 item paper and pencil, true/false test which provided quantifiable data that was used as a measure of student conceptual understanding of personal health and physical fitness. Students were asked to indicate whether an item was true or false, and then provide a written reason for their choice.

The data on conceptual understanding from interviews and open response pencil and paper tests also provided the foundation for the development of a two-tier test that may be used as a diagnostic tool by health education or health science teachers to identify students' misconceptions about health and fitness. Based on these data, commonly reported misconceptions or misunderstandings identified in the interviews and on the true/false test were used to create alternatives for a two-tier multiple-choice test. This two-tier test design (Treagust, 1986) involves: (1) identification of essential science concepts and propositional knowledge statements; (2) interviews using questions based on the propositional knowledge statements; (3) paper and pencil tests to further investigate preconceptions and misconceptions identified in the interviews; and (4) development of a two-tier test that could be used as a diagnostic instrument by classroom teachers.

Student's locus of control was identified from two instruments modified from the Multidimensional Health Locus of Control (MHLC) Scale (Wallston and Wallston, 1978). One instrument, Health Locus of Control, measured students' beliefs about the amount of control they have over their personal health. The second instrument, Fitness Locus of Control, provided data on student's beliefs about the amount of control they have over their physical fitness. The latter instrument was based on items included in the Wallstons' study but was modified to stress fitness rather than health. While personal health and physical fitness are related terms they were each considered separately in this study. Each locus of control instrument was composed of eighteen items. The Health Locus of Control test was designed to examine how strongly students felt about the control of their health in terms of themselves (Internal HLC), powerful others (Powerful Others HLC) or if their health was largely controlled by chance (Chance HLC). Six items were purposefully written for each of these three control forces and students responded on a six point Likert Scale from Strongly Disagree (1) to Strongly Agree (6). The Internal items were scored in the internal direction, i.e. high scores indicated high internal locus of control. The Powerful Others and Chance items were scored in the external direction, i.e. high scores indicated a high external locus of control. For reporting purposes all three scales were scored in the external direction, i.e. internal items were reversed. A similar format was used for the Fitness Locus of Control instrument. Examples of Internal items on the Health & Fitness locus of control respectively were : 'If I become sick I have the power to make myself well again' and 'If I become unfit I can control how soon I become fit again'. Examples of the Powerful Others items were: 'I can only maintain my health by consulting health professionals' and 'Whenever I am unfit I should consult with a trained fitness professional (such as my PE teacher)'. Example of Chance items were: "Even when I take care of myself it is easy to get sick" and "No matter what I do, I'm not likely to become fit".

Data from the locus of control instruments for health and fitness were used, along with student conceptual knowledge scores, to investigate the two questions identified earlier; the relationship between student knowledge and locus of control was also examined.

Health Education Curriculum

Health education programs include many components related to total human well-being. Russell (1981) uses a wellsprings model to illustrate what he calls positive holistic health. The wellsprings include nutritional balance, exercise, mental/emotional balance, heredity, human/spiritual interaction, and ecological balance. In the Western Australian syllabus, health education is an umbrella term that encompasses all the components listed by Russell, though not necessarily using the same terms. Personal health (nutrition) and physical fitness (exercise) are the components of health education addressed in this study.

Sample

The grades 8 and 9 (aged 13-14 years) students involved in this study attended regular health education classes in two metropolitan Perth senior high schools, each with a population of more than one thousand students. Neither school has a selective admission policy and students are drawn from the surrounding area. The students involved in the interviews and open-ended pencil and paper tests on conceptual knowledge of personal health and physical fitness and who responded to the locus of control instruments were from a northern suburb school: Twenty two students from grade 8 were interviewed and 109 students from grade 8 (n = 53) and grade 9 (n = 56) responded to the pencil and paper tests. One hundred and seventy five students from grade 8 (n = 85) and grade 9 (n = 90) in a western suburb school participated in the trialling of the two- tier diagnostic test.

RESULTS AND DISCUSSION

Conceptual Knowledge of Health and Fitness

The interviews provided a range of useful data upon which the twenty items for the true/false questionnaire with open-ended responses were developed. Consequently, the initial Health and Fitness Questionnaire contained 20 items which focussed on personal health concepts, fitness concepts and interrelations between health and fitness concepts. Specifically, these concepts and the number of the item from the test involved:

Personal Health: energy balanced diet [item 2]; dietary intake and being overweight [7]; good eating habits and advertising [8]; loss of weight through dieting [12]; balance between protein foods and fruits/vegetables/cereals [13]; salt in the diet [14]; alcohol and sugar in the diet [15].

Physical Fitness: cardiovascular fitness and physical activity [3]; health fitness and diseases [6]; regular exercise programmes [9]; benefits of regular exercise [10]; fitness and physical wellbeing [19]; fitness and exercise [20].

Health and Fitness: Meaning of healthy and fit [1]; food intake, body size and activity [4]; eating and exercise [5]; weight control and exercise [11]; health and sport [16]; overweight and fitness [17].

Two True/False items illustrating each of the three categories are shown below. Personal health items (number shown in parentheses) were: (2) An energy-balanced diet provides the right number of joules (calories) needed to build and maintain teeth and bones; (14) For many people, large amounts of salt in the diet have been linked with the development of high blood pressure. Physical fitness items were: (3) A person with good cardiovascular fitness can run further and work longer with less effort; (9) Regular exercise for 15-20 minutes a day, three or more times per week, can help keep you physically fit. Health and fitness items were: (1) Being healthy and being fit are the same; (11) Weight control is not affected by physical exercise, it is all a matter of overeating.

An example of a True/False item and the personal health (H) and physical fitness (F) propositional knowledge statements upon which it was based is shown below:

Item 7 : People who are overweight are probably eating too many carbohydrates, fats, and proteins.

H4 : In planning meals and snacks, use all the food groups, avoid too much sugar, salt and fats and count beverages.

F10 : Body fat is formed when extra carbohydrates, fats or proteins are changed and stored.

F12 : Overweight means that a person weighs more than most people of the same age, sex and height. Overfat means a person has too much body fat.

Initial Health and Fitness Questionnaire

From the 20 items of this questionnaire and from the interviews upon which the items were based, a number of misunderstandings about the concepts involved in the Health Education curriculum were identified. The percentage of students with correct responses on each item are presented in column 3 of Table 1. For six items more than 75% of students provided correct answers. Many students confused being personally healthy with being physically fit (Item 1, 52% correct) and thought that being healthy is related to sports, recreation and doing things better (Item 16, 7% correct). Many students also thought that being fit meant not being overweight (Item 17, 67% correct). They also related fitness to big muscles and running without breathlessness. Students did not appear to know of different kinds of fitness and believed that to keep healthy one needs to exercise. Students knew they should exercise but most did not have regular exercise programs. They believed that fat people are not fit and that people who smoke are not fit.

Students know what junk foods are and that they should avoid eating them in excess. However, given a choice of a candy bar or an apple, most would choose the candy bar. In spite of this, they know that excess sugars and fats in their diets are harmful to them. While they know about a balanced diet in terms of the five food groups, they do not know if they are eating according to that prescribed balance and leave that responsibility to their parents. Many students did not know about cardiovascular fitness and some think that running out of breath is losing all their energy. Students knew various exercises and knew that it is possible to over exercise. However, they had no knowledge of cellular metabolism. Many students believed that diets are exclusively for losing weight but others knew about diets, fad diets and that all people do not need the same diet.

Locus of Control Instruments

The Health Locus of Control instrument comprised three scales representing three factors of health locus of control beliefs: internality (IHLC); powerful others (PHLC) and chance (CHLC) externality. Descriptive statistics for the HLC instrument are presented in Table 2 for the grade 8, grade 9 and combined grades. The reliabilities of the total instrument as measured by Cronbach alpha of 0.46 (grade 8), 0.63 (grade 9), 0.59 (Total) for the three groups are low but are comparable with published results with other locus of control instruments. The subscale reliabilities are in the same range of these values. The mean scores for the three groups on the Internal Health Locus of Control were similar and showed that this sample of students had a moderate to high internal locus of control. On the Powerful Others Health Locus of Control the grade 8 group had a significantly more external locus of control (higher score) than did the grade 9 group ($t = 2.44$, $p<0.05$). Similarly, on the Chance Health Locus of Control the grade 8 group had a more external locus of control than did the grade 9 group, but the difference was not statistically significant. For the responses on the total instrument the grade 8 group had a significantly more external locus of control than the grade 9 sample (t = 2.73, $p<0.01$).

The Fitness Locus of Control instrument also comprised three subscales representing three factors of fitness locus of control beliefs: internality (IFLC), powerful others (PFLC) and chance (CFLC) externality. Descriptive statistics for the instrument (Table 3) are consistent with the data on the Health Locus of Control in that the total reliability values were similar (0.62 for the grade 8 sample, 0.59 for grade 9 and 0.60 for the combined sample), as were the subscale reliabilities. There was no statistically significant difference between grades 8 and 9 scores.

On the Fitness Locus of Control instrument, students had a higher internal locus of control (lower (rescaled) scores) than on the Health Locus of Control instrument. For the Powerful Others scale students scored higher than on the Health LOC which represents a more external locus of control for this aspect of fitness than the comparative aspect of health. The Chance scale scores on the Fitness LOC were much lower than on the Health LOC reflecting that these students have a high internal locus of control and do not consider their fitness is due to chance. Overall, students in grades 8 and 9 had a more internal locus of control with regard to physical fitness that towards personal health.

The negatively significant correlation ($r = -0.28$; $p < 0.001$) (Table 4) between the Total Locus of Control Health Instrument and the Total

Health and Fitness conceptual knowledge scores indicates that students with high internal control (those with lower scores) score high on knowledge while those with high external locus of control (those with higher scores) score low on knowledge. A similar relationship ($r = -0.24$; $p<0.001$) existed for the Total Fitness Locus of Control and Student conceptual knowledge of Health and Fitness. Both these statistically significant correlations were accounted for by the relationship between the Chance Locus of Control of the knowledge scores indicating that those students with high knowledge scores had low Chance scores and hence a high internal locus of control.

Health and Fitness Two-Tier Questionnaire

In developing the final instrument, two pilot studies were conducted with secondary students from grades 8 and 9 in one Perth senior high school. Based on these pilot studies involving interviews and open-ended response questions several misconceptions or misunderstandings about health and fitness were identified, and these were incorporated into the response alternatives of the 20 item two-tier test on Health and Fitness.

The first part of each two-tier diagnostic test item consists of a content question requiring a True or False response. The second part of each question contains a set of up to four possible reasons for the answer given in the first part. The reasons consist of the correct answer, and any identified misconceptions or misunderstandings identified in the interviews or pilot studies. Students were required to decide whether or not the statement is true or false and then make one choice from the reason section for each item. Space was also provided for the student to give her/his own reason, when she/he had ideas different from the reasons provided in each of the 20 items. This opportunity for a student to provide her/his own reason for a response helps minimise guessing and can illustrate how strongly a misunderstanding or misconception is ingrained in the mind of the student. These responses also provide the teacher with input for subsequent test revision. The characteristics of the test are summarized in Figure 1.

By means of a specification grid the final instrument was content validated against propositional statements identified as being necessary for defining the health and fitness concepts. The instrument's reliability as measured by Cronbach Alpha was 0.66 when both parts of the items were analysed. Difficulty indices ranged from 0.05 to 0.85, with a mean of 0.52, providing a wide range of item difficulty. Discrimination indices ranged from 0.04 to 0.49 with a mean of 0.36. Two items (#'s 14 and 17) which had low discrimination values and one item (#16) which proved to be very difficult will be revised in later research.

Student responses on each item for the Health and Fitness Two-tier Questionnaire were analysed by grade level and sex for the possible combinations of answer plus reason. Based on the total number of correct answers for both parts of each item there was no statistically significant difference between grades nor between sex and no interaction effects between sex and grade. Since there were no grade differences in performance, the data were combined for analysis and discussion.

The items on the two-tier diagnostic instrument were answered relatively well by both the grade 8 and grade 9 group. Seventy five percent or more of students correctly answered 11 of the 17 items (discounting item 14) for the True/False part of the two-tier test (see column 4 Table 1). However, the correct choice did not always result in a correct reason being selected. For example, while 79% of students in item 3 believed that a person with good cardiovascular fitness can run further and work longer with less effort, almost a fifth of these students believed in the general idea "that any person who is fit and eats correctly can run and work longer" rather than the more specific reason that "a stronger heart can pump blood more easily". In item 9, 78% of the sample correctly believed that "regular exercise for 15-20 minutes a day, three or more times per week, can help keep you physically fit". In item 20, 84% of students believed that "when you run out of breath while exercising, you have just lost all of your energy" was a false statement, but 29% of this sample believed that "you have just not been breathing properly" as being an acceptable explanation for the statement.

Of those remaining 6 items (discounting items 16 & 17) where the student sample scored less than 75% correct for the initial statement, some more obvious misunderstandings or misconceptions became evident:

. 28% of students believed that "an energy-balanced diet provides the right number of joules (calories) needed to build and maintain teeth and bones". (Item 1).

. 30% of students believed that "people who are overweight are probably eating too many carbohydrates, fats and proteins" was a false statement. Of the 70% who believed it to be true, 16%

believed that eating too many fats makes you fat, not eating too many carbohydrates and proteins. (Item 7).

- 40% of students believed that it was not true, that "in general people should eat less protein and more fruit, vegetables and cereals". Almost 42% of these responses selected the response that "protein is in fruit, vegetables and cereals". Of the 60% who selected the correct response to the statement, 45% of responses believed that fruits, vegetables and cereals have all the nutrients your body needs. (Item 13).
- 47% of the sample believed that "alcohol and sugar are nutritious foods that can be a part of your diet program, but only when consumed in moderate amounts". Over 74% of these responses indicated that "you need sugar and alcohol for energy but too much is dangerous". (Item 15).
- 42% of the sample believed that "the only reason for going on a diet is so that you can lose weight" (item 18).

CONCLUSIONS

The results of this study provide useful information about the condition of health education in Western Australia, assuming the sample is representative of the state student population in grades 8 and 9, since the students had a relatively good knowledge of the addressed health education concepts about personal health (nutrition) and physical fitness (exercise). However, when reasons for this knowledge were solicited the percentage correct response for the items dropped considerably and many students' views were incomplete, erroneous or were related to a misconception or misunderstanding. Consequently, this study does provide further evidence of students' misconceptions about health and fitness and addresses the concerns of Brumby et al (1985) about investigating students' understanding of concepts involved in health education.

Compared to student responses on similarly designed items in several science areas (see for example, Haslam and Treagust, 1987; Peterson, Treagust and Garnett, 1987) the incorrect student views on health related concepts were less evident than incorrect concepts in the science areas. Even so, a relatively high number of students provided erroneous reasons (misconceptions or preconceptions) for making decisions about the falsity or truth of a statement related to their personal health or physical fitness. Certainly students do not come to secondary health education classes with a 'tabula rasa' since they have acquired knowledge of values through their elementary schooling, through the media and their family. A knowledge of such erroneous reasoning which students bring to the secondary classroom may be useful to classroom health education teachers when planning lessons about health and fitness. Further research is likely to identify other areas of student understanding which is not consistent with acceptable scientific knowledge and upon which teaching for conceptual change can focus.

Responses to the Locus of Control instruments showed that students in both grades 8 and 9 had a more internal locus of control for their fitness compared to their health. On both instruments students scored highest on the Powerful Other items indicating a more external locus of control for such items. Students who possessed high knowledge scores possessed low locus of control scores (high internality or low fate) for both personal health and physical fitness. Conversely, students who possessed low knowledge scores possessed high locus of control scores (Table 4). This relationship may mean that internality of the locus of control construct can be increased through increased knowledge, but this study has not investigated this relationship. Of further interest would be to investigate the effect of internality of locus of control and increased knowledge on actual student behaviour concerning their personal health and physical fitness.

Overall the health education curricula would appear to be achieving its intended goals. Students were knowledgeable about many of the concepts which were presented to them though they were often unable to offer explanations for their knowledge in terms of acceptable scientific understanding. However, misconceptions and erroneous explanations were encountered less frequently than in reported research in the science education literature. The spiral nature of the health education curriculum in Western Australia has much to recommend it though at the level at which these questions were asked it was surprising that no differences in achievement or locus of control were detected between grades 8 and 9 students. While grade 9 students have had a full year more of the health education curriculum than the grade 8 students, it may be that the conceptual knowledge instrument did not investigate the extra knowledge learned in that year and hence failed to discriminate any learning differences. It would be instructive to administer the knowledge instrument to students upon completion of their elementary schooling (end of grade 7) in order to ascertain the influence of the grade 8 and grade 9 curriculum on their knowledge of personal health and physical fitness.

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Areas Evaluated :	Personal Health and Physical Fitness from Year 8 Health Education syllabus in Western Australia		
Content :	Based on Propositional Knowledge Statements for Personal Health and Physical Fitness Concepts		
Number of Items :	20		
Response Format :	Two-tier multiple choice First tier - content knowledge Second tier - reasons and space for students' own reasons		
Recommended grade level :	8 - 10		
Time to complete test:	30 - 35 minutes		
Discrimination Indices :	Mean	Range	
	0.36	< .20	(2 items)
		.20 - .30	(3 items)
		.30 - .40	(6 items)
		> .40	(9 items)
Difficulty Indices :	Mean	Range	
	0.52	< .20	(3 items)
		.20 - .40	(2 items)
		.40 - .60	(7 items)
		.60 - .80	(7 items)
		> .80	(1 item)
Reliability (Cronbach Alpha) :	.66		

Figure 1 : Test Characteristics of the two-tier Personal Health and Physical Fitness Questionnaire

Table 1

Health and Fitness Questionnaire Data showing mean percentage responses correct on the True-False part of each item

Item	Areas Evaluated	Mean % Correct First Group	 Second Group
1	HF	52	84
2	H	35	72
3	F	72	79
4	HF	85	83
5	HF	95	92
6	F	72	76
7	H	66	70
8	H	62	76
9	F	89	78
10	F	75	84
11	HF	74	81
12	H	97	96
13	H	61	60
14	H	85	92
15	H	39	53
16	HF	7	8
17	HF	67	47
18	H	51	58
19	F	50	73
20	F	75	86

Note:
1. The areas evaluated were personal health (H), physical fitness (F) and a combination of the two (HF).
2. On these items students decided true or false and provided responses (n = 109)
3. On these items students decided true or false and selected responses from the second tier (n = 175)

Table 2

Descriptive data on Health Locus of Control (HLC) Instrument

Scale	No of items	Grade	Mean	s.d.	t-Value	Cronbach Alpha
Internal HLC	6	8	15.04	4.78	1.14	0.66
		9	14.04	4.42		0.51
		8&9	14.52	4.60		0.59
Powerful Others HLC	6	8	20.75	5.05	2.44*	*0.59
		9	18.41	4.99		0.57
		8&9	19.55	5.13		0.60
Chance HLC	6	8	19.34	4.75	1.47	0.40
		9	17.96	5.02		0.55
		8&9	18.63	4.92		0.48
Total	18	8	55.13	8.24	2.73**	0.46
		9	50.41	9.69		0.63
		8&9	52.71	9.28		0.59

* $p < 0.05$
** $p < 0.01$

Table 3

Descriptive data on Fitness Locus of Control (FLC) Instrument

Scale	No of Items	Grade	Mean	s.d.	t-Value	Cronbach Alpha
Internal FLC	6	8	10.38	4.01	-1.38	0.74
		9	11.44	4.05		0.60
		8&9	10.93	4.05		0.67
Powerful Other FLC	6	8	21.92	5.65	0.56	0.72
		9	21.37	4.59		0.48
		8&9	21.64	5.12		0.61
Chance FLC	6	8	12.72	4.41	-1.30	0.64
		9	14.02	5.88		0.72
		8&9	13.39	5.24		0.70
Total	18	8	45.02	8.23	-1.11	0.62
		9	46.84	8.84		0.59
		8&9	45.96	8.56		0.60

Table 4

Intercorrelations between Health and Fitness Knowledge and Health Locus of Control (HLC) and Fitness Locus of Control (FLC)

Locus of Control Instruments	Health and Fitness Knowledge
Internal HLC	0.09
Internal FLC	0.02
Powerful others HLC	- 0.14
Powerful others FLC	- 0.01
Chance HLC	- 0.28**
Chance FLC	- 0.36**
Total HLC	- 0.28**
Total FLC	- 0.24**

** $p < 0.001$

ALTERNATIVE FRAMEWORKS IN ANIMAL CLASSIFICATION

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Young children develop an intense interest in animals before and during the early school years. This interest appears to be an almost universal pnenomenon. In American schools, concepts about animals and their classification are typically introduced in the elementary grades and are "re-visited" in junior high school life science and high school biology courses. Yet, despite the best efforts of good teachers, many children acquire a set of strongly held alternative under standings concerning animal classification. Studies by Bell (1981) in New Zealand, Ryman (1974) in Great Britain, and Natadze (1963) in the Soviet Union suggest that this is not a local problem.

Bell and Bell and Barker (1982) have shown that students of all ages apply the label animal in a highly restricted way, often using it as a synonym for familiar land vertebrates (especially for mammals). Classificatory concepts pose similar problems for many students. Ryman found that the label vertebrate was often applied to animals with well-defined heads and limbs, and invertebrate was used to mean animals with soft or lengthy bodies. Natadze reported that Soviet children commonly classify the whale and dolphin as fish, while bats and other flying mammals are labeled birds.

Problem

The goals of this study were threefold:

1. to identify the alternative frameworks about animal classification that students in Southeastern North Carolina subscribe to;

2. to document the frequency of occurrence of these alternative frameworks across several age groups; and
3. to compare the alternative frameworks held by students in Southeastern North Carolina to those held by students elsewhere.

Method

In keeping with methods developed in previous studies (Arnaudin and Mintzes, 1985), the work was accomplished in two phases. The first phase was inductive in nature, employing clinical interviews and a classification task to explore the range of alternative frameworks that students subscribed to (Trowbridge and Mintzes, 1985). Based on the findings of the exploratory phase, a multiple-choice/free response instrument was developed in order to document the frequency of student ideas in a larger population (experimental phase).

Subjects of the study were enrolled in public schools and a regional campus of a state university in Southeastern North Carolina. They had received no previous instruction in animal classification during the academic year in which this study was conducted.

Exploratory Phase

Subjects were sixty-two students: 21 students were drawn from 5th grade; 20 from 8th grade, and the remainder were freshman/sophomore students enrolled in an introductory college biology course for non-science majors.

Each student was interviewed for approximately 20-25 minutes in the privacy of a small room. In the course of the interview, students were asked to "name five animals," to define "what you mean by the word animal," and to elaborate on the structural and behavioral characteristics of major animal groups.

At the conclusion of the interview, students were given a set of twenty line drawings depicting a diverse group of animals and were asked to classify the drawings into the following categories, as appropriate: invertebrate, vertebrate, fish, amphibian, reptile, bird, and mammal.

Results of the exploratory phase have been reported elsewhere (Trowbridge and Mintzes, 1985). These findings provided the descriptive data which were used in the development of a testing instrument.

Experimental Phase

The testing instrument consisted of 22 items (19 multiple-choice and 3 open ended) which queried students' understanding of animal attributes and classification. The instrument was submitted to a panel of evaluators (biologists, science educators and teachers) who examined each item for consistency with the interview protocol and classification task, and for level and clarity of expression. The revised instrument was found to have an alpha reliability of approximately .50 and a reading difficulty equivalent to the fourth grade level.

The final instrument was subsequently administered to four hundred sixty-eight students at the following levels: 5th grade (N=100); 8th grade (N=100); 10th grade (N=80), and college freshman/sopnomores (non-science majors, N=100 and science majors, N=88).

Results and Discussion

The principal findings of the experimental phase of the study are summarized in Tables 1-9.

When students were asked, "What is an animal? Tell what you mean when you use or hear the word animal," they provided a diverse list of both scientifically-acceptable and alternative attributes (Table 1). In several instances (e.g., "movement"), the frequency of attribution did not change significantly as a function of age or grade level. In others (e.g., appendages, respiration and reproduction), significant shifts were observed. It appears that some of these developmental changes may be consistent with Keil and Batterman's (1984) observations that the acquisition of word meaning involves a shift from reliance on characteristic features ("appendages") to defining features ("reproduction") of a concept. To quote them,

> . . . children's early conceptual representations often tend to be overwhelmed by characteristic features so that the presence or absence of defining features may be completely ignored . . . After the child progresses through some sort of transitional state, the reverse situation holds.

Consistent also with the findings of Bell (1981), our subjects appeared to possess a highly restricted understanding of the concept "animal." As suggested in Tables 2 and 3, the label "animal" seems to be used interchangeably with "vertebrate." When asked to name ten animals, the majority of subjects at all grade levels mentioned only vertebrates. Furthermore, most of the animals named were mammals. (The most frequently mentioned animals were cat, dog, bird, cow and horse). Except for college biology majors, approximately 25% of the subjects failed to identify the fish as an animal, and one-third or more failed to include the butterfly (Table 3).

Although vertebrates appear to be the prototypical animals for most individuals, many of our subjects had difficulty distinguishing between animals that possess a backbone and those that do not (Table 4). For example, a substantial percentage of students at every grade level suggested that the snake is an invertebrate, while many others claimed that the crayfish is a vertebrate.

We believe that the tendency to misclassify certain vertebrate and invertebrate organisms depends on the relative size and perceived importance of certain external morphological features of these animals. Among the most important of these features are segmentation, appendages, and body covering. The snake, for example, may be classified as an invertebrate because it lacks limbs and obvious external segmentation. Similarly, the crayfish is frequently classified as a vertebrate by virtue of its oversized appendages and pronounced segmentation.

In a final series of questions, students were given diverse lists of vertebrate and invertebrate organisms and were asked to identify the fish, amphibians, reptiles, birds and mammals (Tables 5 through 9). A large number of misclassifications were observed. Most appear to be failures to discriminate among closely related organisms possessing ambiguous external morphological features, common habitats or similar behavior patterns. In a few cases, the common name assigned to an organism provides a misleading linguistic cue.

Among the most common misclassifications, the following have the greatest number of adherents:

- the jellyfish, starfish and whale as fish (Table 5).
- the turtle, snake and lizard as amphibians (Table 6).
- the bat as a bird (Table 8).
- the penguin as a mammal (Table 9).

Conclusions and Implications

We have suggested that alternative frameworks in animal classification are widespread and, in some cases, tenaciously adhered to (Trowbridge, 1986; Trowbridge and Mintzes, 1985; submission, 1987). The results of the present study suggest, for example, that alternative notions identified among students in Great Britain and New Zealand are shared by large numbers of Americans.

The sources of conceptual difficulties are not easily identified. It is probable that many of them are products of early childhood experiences and are unintentionally reinforced through formal instruction, subsequent encounters with animals in later life, and through exposure to television and other entertainment media.

The restricted notion of animals as "four-legged, furry creatures" is a prime example. For many children, the earliest exposure to animal-like objects are wooden or plastic toys, stuffed animals and similar objects of affection. Typical pets encountered in the home are dogs and cats. Enriching experiences, such as trips to a farm or a zoo, further confine the range and scope of examples. Commercial television episodes and motion pictures frequently depict emotion-laden events involving horses, dogs and cows.

In keeping with Driver (1983) and Driver and Bell (1986) and others of the constructivist school of learning (Osborne and Wittrock, 1985; Pope and Gilbert, 1985), we have made several suggestions for assisting students to develop scientifically-acceptable meanings in animal classification (Trowbridge and Mintzes, 1987 submission). These suggestions include: early, diverse, multi-sensory experiences, especially with less common vertebrates (reptiles and amphibians) and invertebrates; instructional strategies that help children develop concept prototypes and provide opportunities to practice skills in discrimination and generalization; the use of concept maps and other "metalearning" techniques, and confrontation methods.

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Table 1. What is an Animal?: Traits Most Frequently Mentioned

Traits	Frequency (%) of Response[1]				
	ELEMENTARY (5th Gr)	JR HIGH (8th Gr)	SR HIGH (10th Gr)	COLLEGE (Non-majors)	COLLEGE (Majors)
Alive	32	16	23	34	40
Appendages ("legs, arms . . .")	26	29	6	14	7
Movement	20	24	15	14	26
Heterotrophic ("eats")	14	6	6	12	32
Respiration ("breathes")	5	9	4	22	25
Reproduction	0	4	16	12	31
Not human	14	6	12	16	6
Body covering ("hair, fur, feathers")	14	14	10	10	6

[1] Note: decimal points have been omitted.

Table 2. List the Names of Ten Animals.

Animals Listed	Frequency (%) Response				
	ELEMENTARY	JR HIGH	SR HIGH	COLLEGE (Non-majors)	COLLEGE (Majors)
Only Vertebrates	71	75	66	72	58
More Than 5 Mammals	73	64	66	65	59
At Least 1 Bird	61	68	66	63	68
At Least 1 Reptile	45	46	31	24	49
At Least 1 Fish	35	41	30	25	53
At Least 1 Amphibian	6	14	6	4	13

Table 3. Is This An Animal? (Line drawings depicting organisms listed below).

	Frequency (%) of "Yes" Responses				
Organisms Depicted	ELEMENTARY	JR HIGH	SR HIGH	COLLEGE (Non-majors)	COLLEGE (Majors)
Cow	99	100	100	99	100
Seagull	93	97	91	87	98
Fish	73	74	79	69	90
Butterfly	67	58	63	50	78
Pine	0	0	0	0	0
Mushroom	0	0	0	0	0

Table 4. Does This Animal Have a Backbone? (Line drawings).

	Frequency (%) of "Yes" Responses				
Animals Depicted	ELEMENTARY	JR HIGH	SR HIGH	COLLEGE (Non-majors)	COLLEGE (Majors)
Penguin*	88	94	93	98	99
Whale*	81	87	93	94	92
Bat*	69	82	83	66	91
Snake*	18	44	55	48	63
Crayfish	38	42	31	20	5
Spider	9	10	5	7	1

*Scientifically Acceptable

Table 5. Circle the Fish. (From list below)

Animals Listed	ELEMENTARY	JR HIGH	SR HIGH	COLLEGE (Non-majors)	COLLEGE (Majors)
	Frequency (%) of Animals Circled				
Mackerel*	66	79	91	89	93
Jellyfish	76	62	49	46	15
Starfish	69	58	48	45	14
Whale	54	61	30	41	21
Crab	20	15	13	21	1
Seal	27	15	5	6	1

*Scientifically Acceptable

Table 6. Circle the Amphibians. (From list below)

Animals Listed	ELEMENTARY	JR HIGH	SR HIGH	COLLEGE (Non-majors)	COLLEGE (Majors)
	Frequency (%) of Animals Circled				
Frog*	71	76	84	84	96
Turtle	52	36	50	52	36
Snake	45	51	31	35	19
Lizard	38	43	25	34	23
Snail	36	26	24	23	8
Crab	30	20	25	28	5
Leech	25	27	18	22	10
Seal	30	19	16	21	8
Earthworm	25	23	10	13	5
Eel	18	16	6	21	11
Starfish	13	11	4	11	7

*Scientifically Acceptable

Table 7. Circle the Reptiles. (From list below)

Animals Listed	Frequency (%) of Animals Circled				
	ELEMENTARY	JR HIGH	SR HIGH	COLLEGE (Non-majors)	COLLEGE (Majors)
Lizard*	86	81	85	78	88
Snake*	81	76	89	77	88
Turtle*	50	36	45	33	56
Frog	42	17	14	15	8
Centipede	47	27	9	8	3
Earthworm	36	16	7	7	0
Snail	27	12	6	7	1
Beetle	25	9	6	6	1
Grasshopper	22	8	6	3	1
Leech	20	8	13	1	1
Crab	16	5	5	3	2

*Scientifically Acceptable

Table 8. Circle the Birds. (From list below)

Animals Listed	Frequency (%) of Animals Circled				
	ELEMENTARY	JR HIGH	SR HIGH	COLLEGE (Non-majors)	COLLEGE (Majors)
Seagull*	86	95	91	92	100
Owl*	88	90	90	90	94
Penguin*	77	77	66	59	84
Bat	42	43	30	28	10
Butterfly	13	14	6	3	1

*Scientifically Acceptable

Table 9. Circle the Mammals. (From list below)

Animals Listed	Frequency (%) of Animals Circled				
	ELEMENTARY	JR HIGH	SR HIGH	COLLEGE (Non-majors)	COLLEGE (Majors)
Man*	74	81	85	89	98
Mouse*	67	56	66	49	83
Seal*	52	64	63	58	78
Penguin	39	33	24	34	24
Owl	35	21	18	16	17
Seagull	29	21	18	10	14
Spider	20	12	5	3	1
Grasshopper	20	12	4	3	1
Butterfly	19	10	4	1	0
Beetle	14	13	5	2	1
Ant	13	11	5	3	0

*Scientifically Acceptable

CONSTRUCTING A CONCEPTUAL FRAMEWORK FOR SOLVING A PROBLEM

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The first encounter with problems in genetics presents a challenge for high school or college students. Some students seem to acquire their "secret to a solution" in a reasonably short time; others resort to rules and recall for obtaining answers to limited problem sets; some students never seem to "catch on", but do remember a number of genetic facts.

Problems in elementary population genetics appear to be particularly difficult. Even students who have been successful in solving problems in Mendelian genetics find that they have a good deal to learn. For example, consider the following problem statement and the three questions associated with it:

> The white bulb color in onions is a genetically determined phenotype controlled by a pair of recessive alleles. The white allele (r) is recessive to the red allele (R). The phenotypes of 100 onions, which arose from a chance union of gametes, are given below:
>
> 51 have red bulbs
> 49 have white bulbs
>
> 1. What proportion of the bulbs are red?
> 2. What is the proportion of white alleles in the population?
> 3. What proportion of onions inherited two red alleles?

Almost every student gives a correct answer to the first question even without instruction in genetics, but only about half of the students in an introductory college

biology course can correctly answer the last two questions even after instruction.

A simple change in the problem statement will result in a change in the proportion of students that correctly answer each question. If the problem statement is changed to read:

> ... The genotypes of 100 onions ... are given below
>
> 9 are RR
> 42 are Rr
> 49 are rr

and the same questions are asked, then Question 1 becomes more difficult than it was in the original context, Question 2 becomes easier, and Question 3 is a "give-away". Other changes are observed if the problem statement contains only information concerning allele frequencies.

Why does a context change result in changes in question difficulty? How do students learn to solve such problems? What conceptual difficulties do students display? How do various types of knowledge interact to produce a solution to the problems presented to students? The study that follows explores these questions.

CONCEPTUAL DIFFICULTIES IN SOLVING PROBLEMS

Simple tests of understanding (Murray, 1986) were used to reveal the conceptual difficulties displayed by students as they encounter problems in population genetics. Each test consisted of three problem statements, each of which was followed by seven questions. A sample test is provided in Appendix I. Seven of the 21 questions could be answered by simply referring to the information provided in the problem statement. These questions were interpreted as being directly related to language skills and provide some indication of the errors associated with "hasty reading".

Fourteen questions were used to characterize student conceptions of phenotypes, genotypes, and alleles as applied to population genetics problems. A student who seems to understand how to solve a problem that centers around a given concept is said to have a clear and stable concept. Four categories of misunderstanding can be identified by analyzing response patterns to all questions for which a given concept can be correctly or incorrectly applied. These categories of misunderstanding are called undergeneralization, overgeneralization, misconception, and confusion. A sixth category, called omission, refers to an individual who shows no evidence of using a given concept.

The conceptual difficulties displayed by 210 students during problem solving are shown in Figure 1. Prior to instruction, about two-thirds of the population displayed misconceptions of phenotypes (68%); a similar proportion had misconceptions of genotypes (67%). A very small proportion came to instruction with clear and stable conceptions of either of these ideas — phenotypes (2%), genotypes (1%). After instruction, about one-fourth of the students could understand and use concepts of genotypes (26%); a similar proportion (25%) had clear and stable conceptions of phenotypes. However, about two-fifths of the students still held misconceptions of genotypes (44%); a similar proportion displayed misconceptions of phenotypes (40%).

Prior to instruction, the majority of students had either a misconceived (37%) or a confused (35%) conception of alleles. Only about 3% had a clear and stable understanding of this concept. After instruction, the proportion of

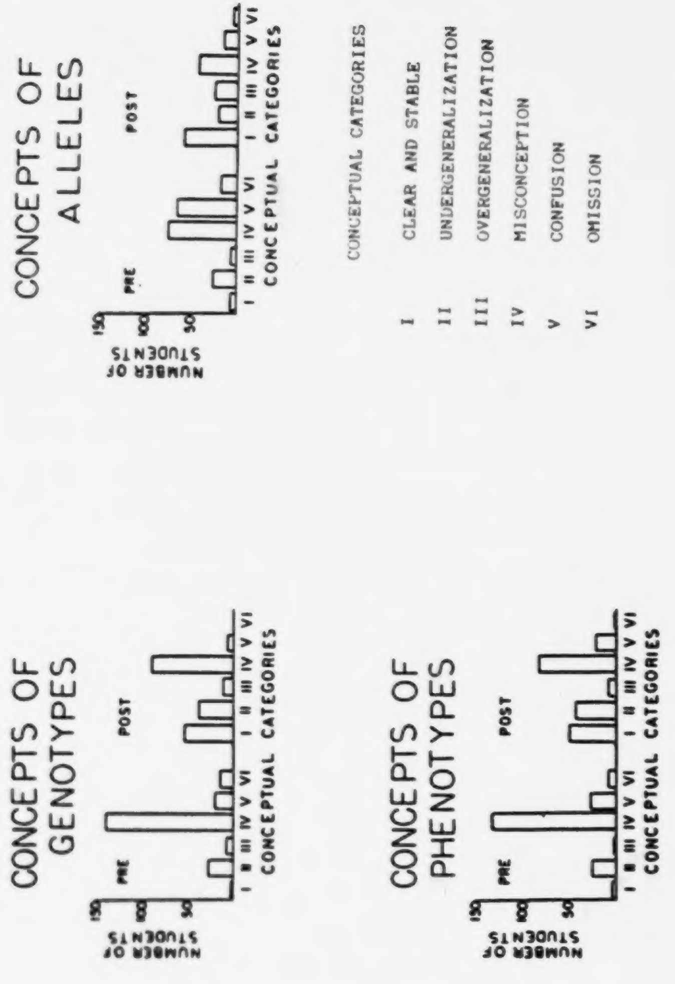


FIGURE 1: Conceptual difficulties displayed by students during problem solving (n=210). Note the similarity of distributions for concepts of genotypes and phenotypes; students have a comparable level of understanding of these two concepts.

students displaying a clear and stable concept of alleles increased to one-third of the population. A substantial proportion still held misconceptions (28%).

Clearly, learning to solve problems in population genetics is not an easy task. Problem solving must require a significant amount of knowledge.

A KNOWLEDGE MODEL OF PROBLEM SOLVING

Several investigators have published studies on difficulties experienced by students in solving Mendelian genetics problems. These difficulties have been attributed to undeveloped reasoning skills (Walker *et al*., 1979; 1980), over reliance on rules and recall (Kinnear, 1983), misconceptions (Stewart, 1982; Kinnear, 1983), inadequate knowledge of relations between concepts or terms (Longden, 1982; Stewart, 1982; Tolman, 1982), and ineffective strategic or heuristic knowledge (Smith and Good, 1984). Each of these studies points to the importance of several types of knowledge in solving genetics problems. However, these research efforts have not explored how each kind of knowledge contributes to solving a problem.

A categorical model of problem solving in mathematics appears to provide an explicit way of examining how various types of knowledge interact to produce a solution to a problem (Mayer, 1983). This model of how one solves problems refers to the existence of five kinds of knowledge. The model goes something like this:

> When presented a problem to solve, one must *translate* the words of a problem into some sort of representation. *Linguistic knowledge* allows one to read the problem and identify the question asked. *Semantic* or *factual knowledge* deals with the terminology and subject matter involved in solving the problem. A schema or *schematic knowledge* provides a representation of the concepts necessary to understand the problem and guide a solution.
>
> The *solution* stage of problem solving entails two more kinds of knowledge. *Procedural knowledge* involves the basic mathematical operations used to solve the problem. *Strategic knowledge* is the general problem solving technique applied to sequencing the solution path.

A central feature of the model lies in the construction of a SCHEMA. At its most basic level, a schema includes concepts and the relations between them. Early research efforts focused on constructing an explicit representation of the relations between concepts. The seven concepts necessary for understanding population genetics problems have been identified and the relations between them have been specified. A schema for understanding and guiding problem solving in population genetics is given in Figure 2.

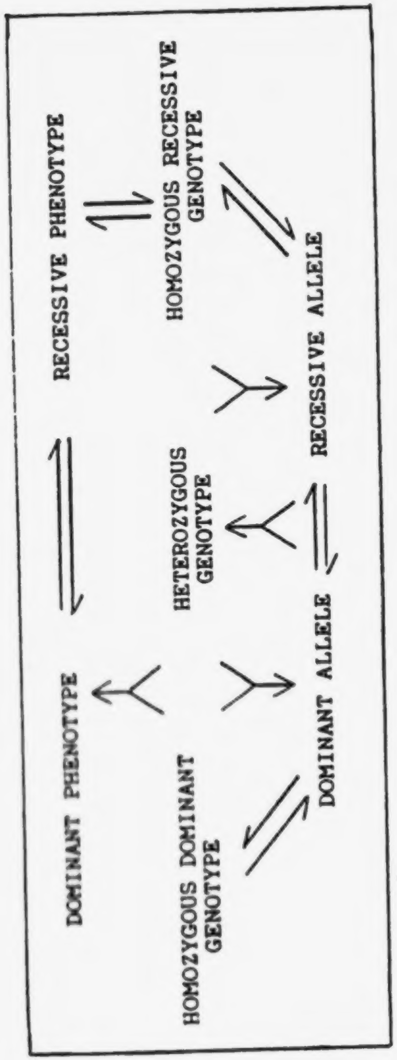
A SCHEMA AS PREDICTOR OF QUESTION DIFFICULTY

Why are some population genetics questions easier to answer than others? Can a schema be used to predict question difficulty?

Some traditional ideas about problem solving suggest that more difficult questions require a larger number of "solution steps" than do less difficult ones. Our schema allows us to count the number of "steps" entailed in going from one part of the network to another. By determining the conceptual information given in the problem statement and the equivalent information asked for in the question, we

FIGURE 2:

A SCHEMA FOR UNDERSTANDING POPULATION GENETICS PROBLEMS INVOLVING DOMINANCE



Words represent concepts.
Arrows represent relations between concepts.

should be able to arrange the questions according to a predicted difficulty.

For example, if a question requires simply finding that information in the problem statement, then the problem can be defined as a "zero step problem". More difficult problems would be expected to have longer "solution lengths". Problems of varying solution lengths can be quantitatively defined by simply counting the number of steps (arrows) between a particular given and a specified goal.

An early prediction made from the schema was that the difficulty of a problem would be an inverse function of solution path length; in qualitative terms this function was seen as being similar to a "radioactive decay curve" in physics or a "type III survivorship curve" in population biology. To test the predictive validity of the schema, 21 problems were examined. The number of steps for each question was determined using the problem statement, question asked, and the schema. Seven problems were classed as 0 step, eight as 1 step, and two each for 2, 3, and 4 step problems. A graph of the proportion of correct answers (vertical axis) versus number of steps (horizontal axis) is given in Figure 3.

The proportion of correct answers is related to solution path length. Problems involving longer solution paths are more difficult. As a first order approximation, a schema can be used as a predictor of question difficulty.

On both the pretest and posttest, a higher proportion of students correctly answered 0 step problems when compared with 1 or more step problems (p values ranged from less than 0.00005 to 0.0025). There were no significant differences

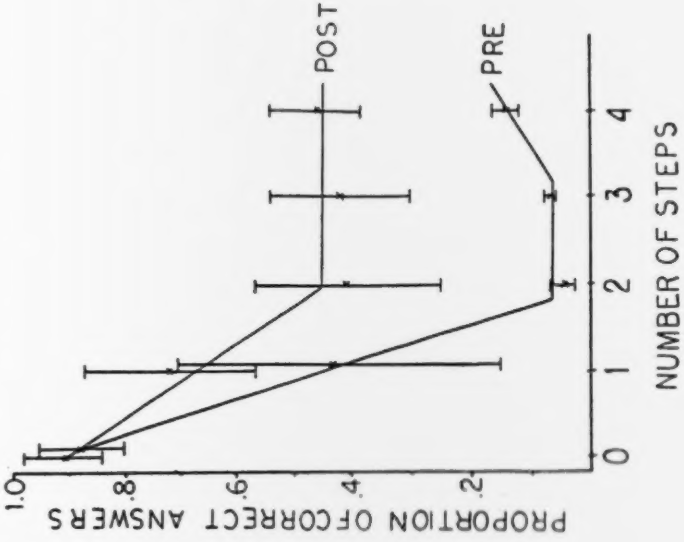


FIGURE 3: Graph of proportion of correct answers as related to solution path length. Students score significantly higher on the posttest than on the pretest for items requiring solutions of 1 or more steps. Items requiring longer solutions are more difficult.

between the two tests for questions designed to indicate linguistic knowledge (0 step problems). On the pretest, problems requiring 4 steps to solution appear to be easier than those requiring 2 or 3 steps ($p = 0.0416, 0.0417$); however, question difficulties are at the chance level of response. On the posttest, scores are significantly higher on 1 step than on multi-step problems ($p = 0.032$ to 0.0507). The variation in question difficulties in 1 step problems on the pretest is great, ranging from 0.75 to 0.09; this observation suggests further experiments with regard to procedural knowledge.

RELATIONS BETWEEN FACTS AND A SCHEMA

Students encounter a number of facts in their attempts to solve population genetics problems. Some facts are simple rules of convention; such as, a capital letter stands for the dominant allele or q is the frequency of the recessive allele. Other facts, such as the frequency of the dominant phenotype is calculated as the sum of the homozygous dominant and heterozygous genotype frequencies or $p^2 + 2pq$, include a procedural component. Do successful problem solvers simply learn more facts than those who are not successful? Or are there differences in the ways these two groups organize factual knowledge?

The knowledge model states that a schema is used to organize facts. It is assumed that specific information, such as contained in a fact, is linked to the underlying elements of a schema. If a schema acts to arrange facts in a particular fashion, can it be used to distinguish more important from less important facts as indicated by problem solving success on a particular problem?

A preliminary experiment was conducted to establish the relations between facts and a schema in the context of problem solving success. The data from this experiment have not been completely analyzed and the experiment needs to be replicated and extended. Our results are preliminary, but quite suggestive that successful problem solvers are actually using their own schema in solving problems.

The test we used in this experiment contained 5 problems and 20 facts. A sample test is provided in Appendix II. Some facts included were:

p equals the frequency of the dominant allele.
L symbolizes the dominant allele.
The frequency of the dominant phenotype is calculated as the sum of the homozygous dominant and heterozygous genotype frequencies.

All of the 20 facts could be related to each of the 5 problems. Item correlations by contingency analysis allowed us to identify those facts most closely associated with each problem. Successful and unsuccessful problem solvers could be identified for each problem. The facts that discriminated between these two groups of problem solvers were declared as being important if the level of statistical significance was less than 0.01. Chi square values were used to rank order important facts held by 161 students.

Our preliminary findings indicate that the most important facts for successful problem solving are NOT those directly expressed in arriving at a solution. For example, when students were presented a problem statement that gave allele frequencies and were asked to determine the frequency of the HETEROZYGOUS GENOTYPE, the rank order of important facts was found to be:

LL + Ll (1)
$p^2 + 2pq$ (2)
Calculated as the sum of the homozygous dominant and heterozygous genotype frequencies (3)
Calculated as the sum of the square of the dominant allele frequency plus the product of 2 (dominant allele frequency) (recessive allele frequency) (4)
Symbolized as L (5)

The first four information strings are linked to the concept of DOMINANT PHENOTYPE and the fifth (5) string is linked to the concept of DOMINANT ALLELE. None of the above facts are directly related to the solution of the problem.

Similar results were obtained for all 1 and 2-step questions in this problem set. For example, when students were asked for the frequency of the HOMOZYGOUS DOMINANT GENOTYPE, the rank order of important facts was found to be:

Calculated as the sum of the homozygous dominant and heterozygous genotype frequencies (1)
Calculated as the product of 2 (dominant allele frequency) (recessive allele frequency) (2)
Symbolized as L (3)
Calculated as the square of the dominant allele frequency (4)

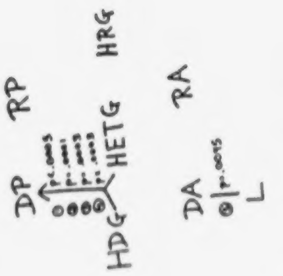
These information strings are associated with four of the seven concepts in the schema. Only the last fact — the frequency of the homozygous dominant genotype is calculated as the square of the dominant allele frequency — is directly involved in the solution to the problem. Figure 4 summarizes the above findings and relates the important facts to a schema.

The results of this experiment make sense only when viewed in the context of a schema that serves to order

FIGURE 4: Rank order of important facts which discriminate between successful and unsuccessful problem solvers (n=161)

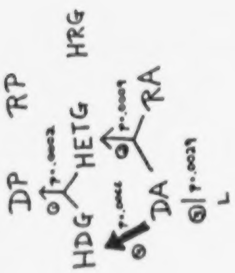
Students were presented a problem statement that gave allele frequencies and were asked to determine the frequency of the HETEROZYGOUS GENOTYPE

FACT STATEMENT	CONCEPT	X^2	P VALUE	RANK
LL + Ll	DP	18.56	<.00005	1
$p^2 + 2pq$	DP	16.01	.0001	2
Calc as sum HDG + HETG	DP	13.3	.0003	3
Calc as sum of square DA + 2(DA)(RA)	DP	13.1	.0003	4
Symbolized as L	DA	8.062	.0045	5



Students were presented a problem statement that gave allele frequencies and were asked to determine the frequency of the HOMOZYGOUS DOMINANT GENOTYPE

FACT STATEMENT	CONCEPT	X^2	P VALUE	RANK
Calc as HDG + HETG	DP	14.0	.0002	1
Calc as 2(DA)(RA)	HETG	10.93	.0009	2
Symbolized as L	DA	8.85	.0029	3
Calc as square of DA	HDG	7.38	.0066	4



facts. It is as if in order to solve a problem one must know which other problems NOT to solve. The most important facts in problem solving often serve to define the boundaries of the problem, thus indicating what to attend to. By constraining the problem in a fashion that allows one to seek the facts directly entailed in a solution, a schema may serve a function conventionally assigned to strategic knowledge.

A SCHEMA AS AN ELEMENT OF MEMORY

Do successful problem solvers carry around a schema of population genetics in their memory? A powerful method for examining this question has been invented by Novak and his colleagues (Novak and Gowin, 1984). The technique called concept mapping has been described as follows:

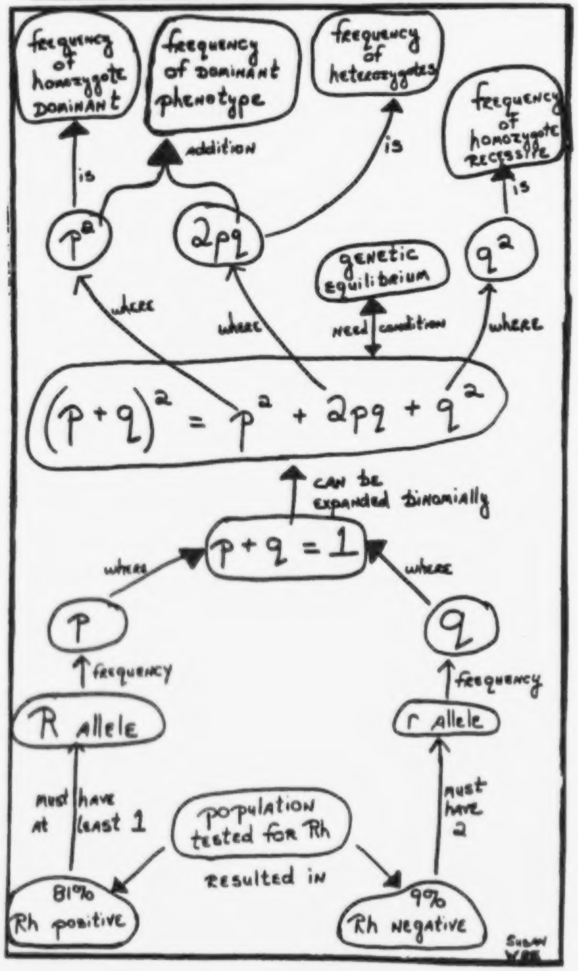
> A concept map is a schematic device for representing a set of concept meanings embedded in a framework of propositions. ... After a learning task has been completed, concept maps provide a schematic summary of what has been learned. ... Concept mapping is a technique for externalizing concepts and propositions.

In order to learn more about a schema as an element of memory, graduate students who were familiar with concept mapping techniques were presented a population genetics problem and asked to construct a concept map that could be used to solve the problem. Figure 5 shows the problem and the concept map constructed by a student who was a successful problem solver.

In general, student generated concept maps differ from the schema used in this study in at least two ways. First, student maps are presented in propositional form whereas the

FIGURE 5: Concept map constructed by a graduate student to solve a population genetics problem

In a particular population, the people were tested for having Rh positive and Rh negative blood. Rh negative blood results from the inheritance of a pair of recessive alleles (rr). The Rh positive allele (R) is dominant. It was found that 9% of the population had Rh negative blood. Assuming this population is in genetic equilibrium, what is the frequency of the dominant allele? The frequency of heterozygotes? The frequency of the dominant phenotype?


frequency of homozygote DOMINANT
frequency of DOMINANT phenotype
frequency of heterozygotes
frequency of homozygote RECESSIVE
is
addition
is
is
p^2
$2pq$
genetic equilibrium
q^2
where
where
need condition
where
$(p+q)^2 = p^2 + 2pq + q^2$
can be expanded binomially
where
$p+q=1$
where
p
q
frequency
frequency
R Allele
r Allele
must have at least 1
must have 2
population tested for Rh
resulted in
81% Rh positive
9% Rh negative

schema is not. The propositional form of student maps is in part a constraint of the mapping technique that students learn, but more importantly, it reflects the instruction that students receive while learning to solve population genetics problems. Second, students who are successful problem solvers invariably include some version of the algebraic formulation, attributed to Hardy and Weinberg, that serves as the primary vehicle for instruction in elementary population genetics. This algebraic formulation, known as the Hardy-Weinberg law, plays a major role in anchoring the concepts of genetics expressed in our schema.

Students who are successful at solving population genetics problems construct concept maps that are similar to the schema used in this study. Their maps are less generalized and have a strong procedural component.

OTHER QUESTIONS CONCERNING A SCHEMA

How does procedural and strategic knowledge interact with a schema? Can basic operators be incorporated into a schema? If so, will a schema of concepts and operators reveal the links between concepts and operations that can be examined by following solution paths made by students? What role does strategic knowledge play in solving population genetics problems? Can a schema with its associated operators be used to predict the presence of different strategies used by students in sequencing a solution to a problem?

Although concepts and relations between concepts are necessary to understand a problem, they are not sufficient to guide numerical solutions. Population genetics problems require the use of arithmetical operations in arriving at a solution. For a schema to be useful in understanding and solving problems in population genetics, it must include concepts, relations, and operators. Our latest version of such a schema views concepts and operators (also called concepts by mathematicians) as forming a network. A conceptual network for guiding solutions to population genetics problems is shown in Figure 6.

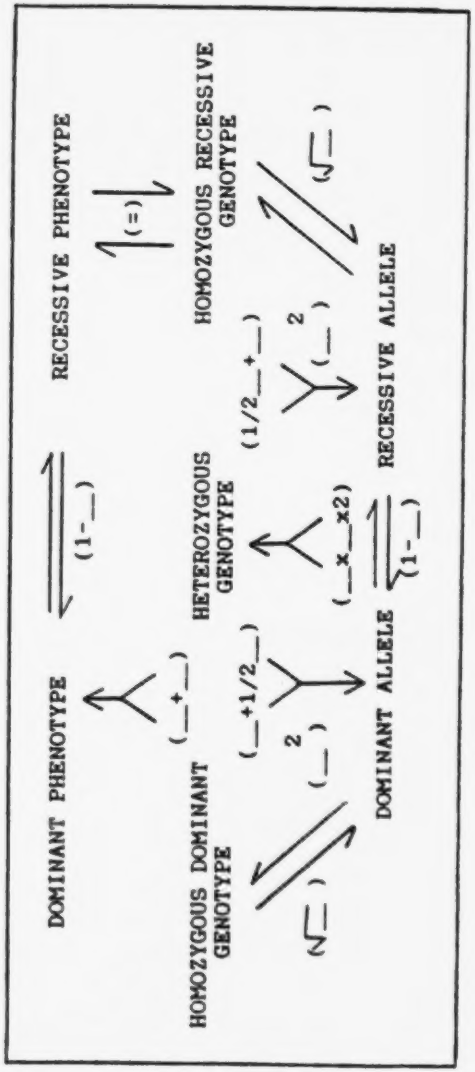
The procedural knowledge entailed in arriving at a numerical solution to a population genetics problem involves such basic mathematical computations as addition, subtraction, multiplication, squaring a decimal fraction, and taking the square root of a decimal fraction. Our next experiments will examine student performance with these operations.

Preliminary results indicate that all but a few students appear to be capable of performing the arithmetical operations entailed in seeking a solution to a problem. However, the capacity for performing an operation and knowing when to perform it remains a challenge for many students. This observation is clearly illustrated by examining student solutions to problems involving a simple operation for successful solution. When students are given genotypic information and asked a question concerning the frequency of the recessive phenotype, a simple solution is to recognize the equivalency of the frequencies of the homozygous recessive genotype and the recessive phenotype. In other words, the frequencies of these two genetic classes are equal.

Students were given the above problem and asked to include their thoughts and calculations along with a numerical answer. The words, symbols, and calculations that

FIGURE 6:

A CONCEPTUAL NETWORK FOR SOLVING POPULATION GENETICS PROBLEMS



Words represent concepts.
Arrows represent relations between concepts.
Symbols represent operations on concepts.

they gave allows one to reconstruct a solution path for all but a few students. An examination of the solution paths provided by 75 students revealed that 46 used a simple equivalency operation in arriving at a successful solution; 6 other successful problem solvers used more complex operations. The 23 unsuccessful problem solvers that provided solution paths also used more complex operations. 12 students had added existing or appropriately modified genotypic classes and 11 students had incorporated a square root operation in their solution path. It is interesting to note that all but 3 of these students had solved a population genetics problem, but NOT the one requested by the question that they were asked! 9 students calculated the frequency of the recessive allele; 7 the frequency of the dominant phenotype; and 4 the frequency of the dominant allele.

We are currently extending our analysis to include a larger sample size and a study of operations in 2, 3, and 4 step problems. However, even these preliminary results indicate that operational skills, although sometimes flawed, do not stand as a major "cause" of problem solving difficulties, at least for the one step problems that we have studied.

A major source of problem solving difficulty lies in the conjunction of operations with genetic concepts. Learning when to use a particular operation or set of operations appears to be a matter of understanding the genetics. The interfacing of operations and concepts will be highly dependent on adequate conceptual underpinnings either in the form of rules or a schema. The evidence gathered in our exploration of the relations between facts and a schema suggests that the latter is most likely to provide the strongest base for successful problem solving.

The use of strategic knowledge in solving a problem is related to the sequencing of goals and subgoals in arriving at a solution. The role of strategic knowledge in solving population genetics problems is largely unknown at this time. Past investigations on the use of strategic knowledge in problem solving have focused on the analysis of solution paths. Our largely unanalyzed data indicates that successful problem solvers employ a limited number of "strategies" in arriving at a solution. However, the vast majority of these strategies are predictable based on the postulated schema. It is also clear that unsuccessful problem solvers employ a rich diversity of "strategies", some of which lead to such "novel solutions" that they are quite difficult for us to understand.

Our expectations are that both procedural and strategic knowledge will interact with schematic knowledge. In addition, we anticipate that the schema we have constructed will assist us in exploring this interaction.

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APPENDIX I: 21 item multiple choice test designed to determine language skills and to characterize conceptions of genotypes, phenotypes, and alleles as applied to population genetics problems

TEST FORM FF

POPULATION GENETICS

This is a 21 question multiple choice quiz covering population genetics. Each of the possible answers located to the left of the questions may be used once, more than once, or not at all. Place your answers to each of the questions on the IBM answer sheet. Be sure to use a pencil. Write your answers and any calculations on this test form.

Place the following information on the IBM answer sheet and this test form:

1. Your name
2. Your Social Security Number
3. Discussion section number and lab instructor's name
4. Test Form Letter (EE, FF). See upper right corner of page.

A population of rabbits exhibits two phenotypes of coat color controlled by a pair of alleles. The black allele (B) is dominant over the brown allele (b). The 100 rabbits in the population have the following genotypes:

9 are BB
42 are Bb
49 are bb

a) 0.09
b) 0.25
c) 0.30
d) 0.42
e) 0.49
f) 0.50
g) 0.51
h) 0.70
i) 0.75
j) 0.91

1. What proportion of rabbits inherited two brown alleles?
2. What proportion of rabbits inherited two black alleles?
3. What proportion of rabbits inherited one black and one brown allele?
4. What proportion of rabbits have brown coats?
5. What proportion of rabbits have black coats?
6. What is the proportion of brown alleles in the population?
7. What is the proportion of black alleles in the population?

(see next page)

- PAGE 2 -

TEST FORM FF

The white bulb color of onions is a genetically determined phenotype controlled by a pair of recessive alleles. The white allele (r) is recessive to the red allele (R). The phenotypes of 100 onions, which arose from a chance union of gametes, are given below:

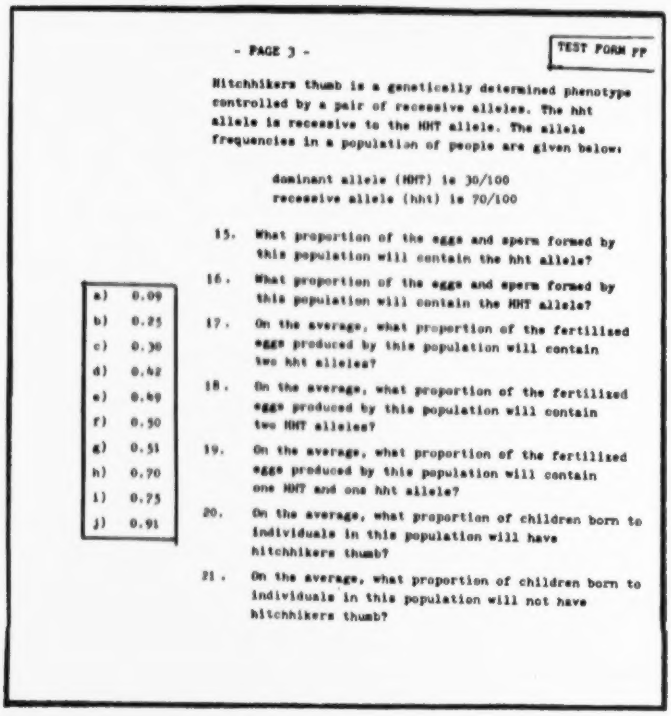
51 have red bulbs
49 have white bulbs

a) 0.09
b) 0.25
c) 0.30
d) 0.42
e) 0.49
f) 0.50
g) 0.51
h) 0.70
i) 0.75
j) 0.91

8. What proportion of bulbs are white?
9. What proportion of bulbs are red?
10. What is the proportion of white alleles in the population?
11. What is the proportion of red alleles in the population?
12. What proportion of onions inherited two white alleles?
13. What proportion of onions inherited two red alleles?
14. What proportion of onions inherited one red and one white allele?

(see next page)

APPENDIX I: 21 item multiple choice test designed to determine language skills and to characterize conceptions of genotypes, phenotypes, and alleles as applied to population genetics problems



- PAGE 3 -

TEST FORM PP

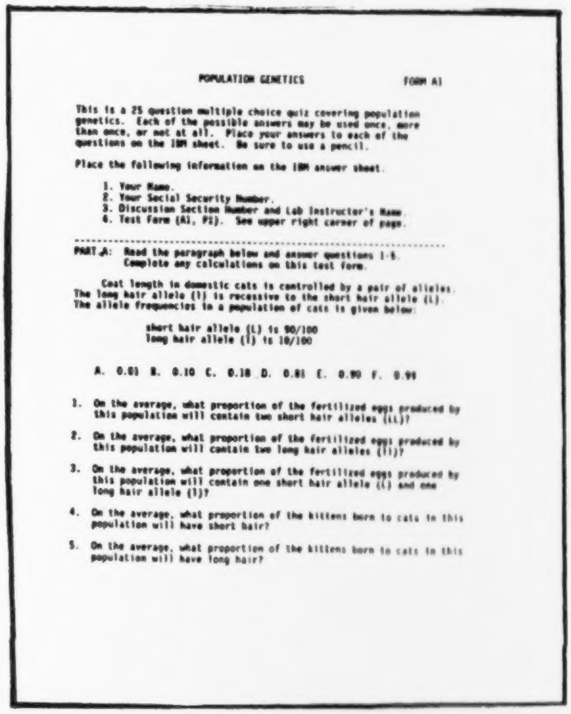
Hitchhikers thumb is a genetically determined phenotype controlled by a pair of recessive alleles. The hht allele is recessive to the HHT allele. The allele frequencies in a population of people are given below:

dominant allele (HHT) is 30/100
recessive allele (hht) is 70/100

a) 0.09
b) 0.25
c) 0.30
d) 0.42
e) 0.49
f) 0.50
g) 0.51
h) 0.70
i) 0.75
j) 0.91

15. What proportion of the eggs and sperm formed by this population will contain the hht allele?
16. What proportion of the eggs and sperm formed by this population will contain the HHT allele?
17. On the average, what proportion of the fertilized eggs produced by this population will contain two hht alleles?
18. On the average, what proportion of the fertilized eggs produced by this population will contain two HHT alleles?
19. On the average, what proportion of the fertilized eggs produced by this population will contain one HHT and one hht allele?
20. On the average, what proportion of children born to individuals in this population will have hitchhikers thumb?
21. On the average, what proportion of children born to individuals in this population will not have hitchhikers thumb?

APPENDIX II: 25 item multiple choice test designed to establish the relations between facts and a schema



POPULATION GENETICS FORM A1

This is a 25 question multiple choice quiz covering population genetics. Each of the possible answers may be used once, more than once, or not at all. Place your answers to each of the questions on the IBM sheet. Be sure to use a pencil.

Place the following information on the IBM answer sheet.

1. Your Name.
2. Your Social Security Number.
3. Discussion Section Number and Lab Instructor's Name.
4. Test Form (A1, P1). See upper right corner of page.

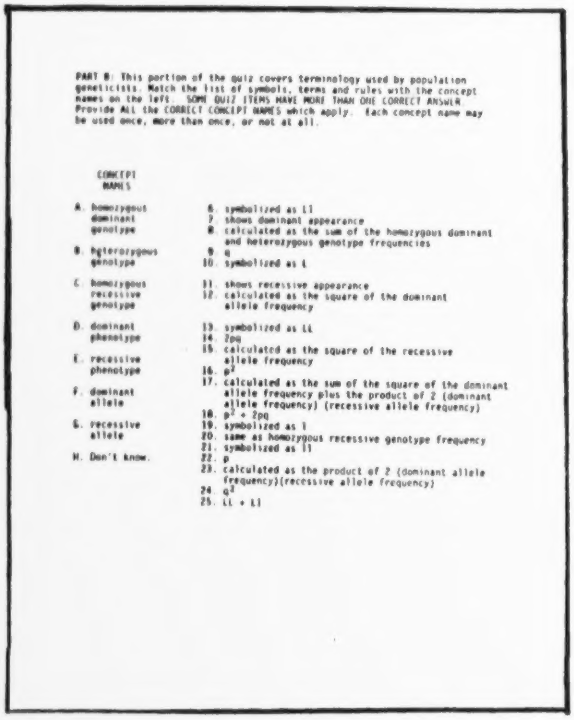
PART A: Read the paragraph below and answer questions 1-5.
Complete any calculations on this test form.

Coat length in domestic cats is controlled by a pair of alleles. The long hair allele (l) is recessive to the short hair allele (L). The allele frequencies in a population of cats is given below:

short hair allele (L) is 90/100
long hair allele (l) is 10/100

A. 0.01 B. 0.10 C. 0.18 D. 0.81 E. 0.90 F. 0.99

1. On the average, what proportion of the fertilized eggs produced by this population will contain two short hair alleles (LL)?
2. On the average, what proportion of the fertilized eggs produced by this population will contain two long hair alleles (ll)?
3. On the average, what proportion of the fertilized eggs produced by this population will contain one short hair allele (L) and one long hair allele (l)?
4. On the average, what proportion of the kittens born to cats in this population will have short hair?
5. On the average, what proportion of the kittens born to cats in this population will have long hair?



PART B: This portion of the quiz covers terminology used by population geneticists. Match the list of symbols, terms and rules with the concept names on the left. SOME QUIZ ITEMS HAVE MORE THAN ONE CORRECT ANSWER. Provide ALL the CORRECT CONCEPT NAMES which apply. Each concept name may be used once, more than once, or not at all.

CONCEPT NAMES

A. homozygous dominant genotype
B. heterozygous genotype
C. homozygous recessive genotype
D. dominant phenotype
E. recessive phenotype
F. dominant allele
G. recessive allele
H. Don't know.

6. symbolized as Ll
7. shows dominant appearance
8. calculated as the sum of the homozygous dominant and heterozygous genotype frequencies
9. q
10. symbolized as L
11. shows recessive appearance
12. calculated as the square of the dominant allele frequency
13. symbolized as LL
14. 2pq
15. calculated as the square of the recessive allele frequency
16. p^2
17. calculated as the sum of the square of the dominant allele frequency plus the product of 2 (dominant allele frequency) (recessive allele frequency)
18. $p^2 + 2pq$
19. symbolized as l
20. same as homozygous recessive genotype frequency
21. symbolized as ll
22. p
23. calculated as the product of 2 (dominant allele frequency)(recessive allele frequency)
24. q^2
25. LL + Ll

A TEACHING STRATEGY BASED ON STUDENTS' ALTERNATIVE FRAMEWORKS
- THEORETICAL CONCEPT AND EXAMPLES

Hans Niedderer

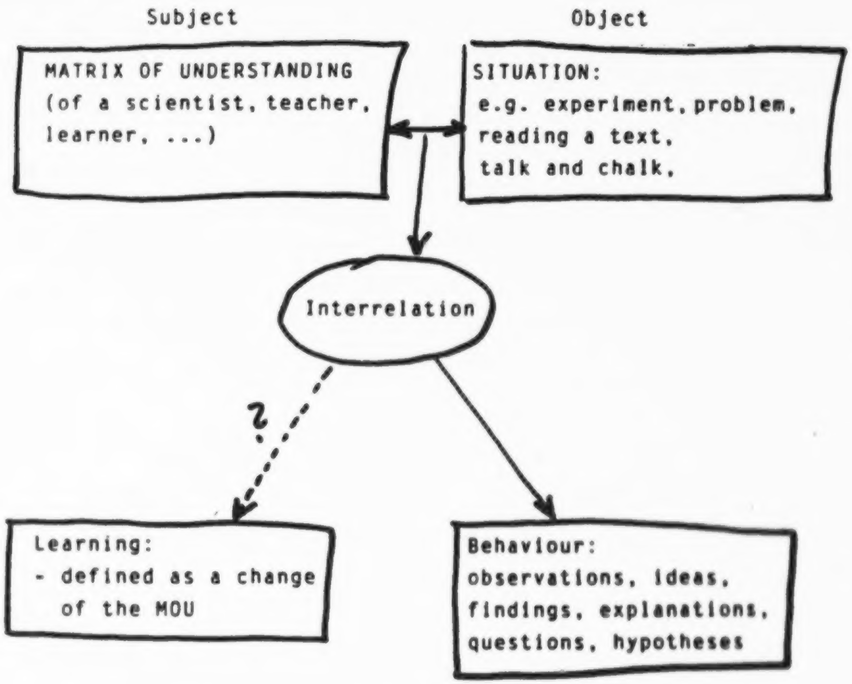
University of Bremen, F.R. of Germany

1. Our Position Concerning Philosophy of Science

Starting from a teaching project "Theory of Science and Physics Teaching", we have tried to apply the results of the so-called "New Philosophy of Science" (Brown 1977) to our research of science teaching. From the works of Kuhn (1976), Lakatos (1974), Holzkamp (1968) and others we have learned that the process of knowing in physics is determined by belief systems concerning relevant subject matter, goals and methods which guide the acts of discovery (e.g. experiments). While Kuhn speaks of "paradigms" or "disciplinary matrices" and Lakatos of "research programs" - concepts aiming at scientific communities - we call the corresponding ensemble of cognitive guidelines referring to the individual subject in a process of discovery or learning the individual "matrix of understanding (MOU)" (cf. Niedderer 1975, Redeker 1981, v.Weizsäcker 1985, Schecker 1985).

An individual matrix of understanding (MOU) is the corpus of all dispositions that influence the way a person deals with a certain group of phenomena or problems. When a person ("subject") is confronted with a problem ("object"), certain dispositions from this set are activated and influence observations or the formulation of findings.

Thus we arrive at the following model for the process of thinking or learning:


Subject
Object
MATRIX OF UNDERSTANDING (of a scientist, teacher, learner, ...)
SITUATION: e.g. experiment, problem, reading a text, talk and chalk,
Interrelation
?
Learning: - defined as a change of the MOU
Behaviour: observations, ideas, findings, explanations, questions, hypotheses

(Matrix of understanding (MOU) $\approx$ alternative framework)

The matrix of understanding (MOU) is a hypothetical construct. Its postulation can be justified by showing it to be a valid instrument for interpreting and understanding students' behaviour, especially their difficulties in learning.

Our main point concerning this model is that scientific theories cannot be developed just by making exact experiments following the principle of induction. The relation between theory and experiment is better described by the principle of realization (Holzkamp 1968) which says, that experiments often have the purpose of finding a possible realization for a theory already in mind. When we look at the work of scientists in laboratories this seems to be a great deal of their activities.

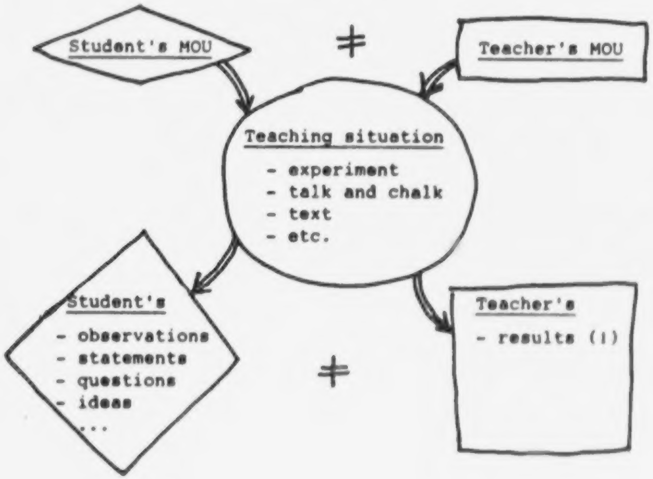
2. Analysis of the Teaching Process

When we look at science teaching with this model, the basic fact is that the matrix of understanding (MOU) of the teacher is very different from the students' MOU. The teacher

- knows the findings (e.g. of an experiment)
- likes to arrive quickly at these findings
- has in general an empiristic view of science ("each experiment leads to one specific theory", cf. Krüger, Schecker 1982)
- aims at forming a generalized scientific view of the problems discussed, often working directly with mathematical language.

In contrast to that students start from tentative explanations, more related to everyday life, to practical purposes and concrete findings for specific situations. We will give some more discussion of those differences below.

This leads to the following situation:



The consequence is: A student following the teaching process employs his ideas and necessarily arrives at questions, observations, and findings which are different from those of the teacher. If the instruction follows a straight course and the teacher' s findings are immediately called the result, the student must be confused. He will react in one of these four ways:

- He or she resigns (Later statements: "I have never understood physics", "physics is too difficult for me", etc.),
- He or she learns to "switch-off" own ideas, learns to guess what teachers' (or scientists') ideas are like and gets used to them (the "brilliant student").
- He or she disturbs the teaching process.
- He or she starts to argue against the teacher (this is rare and the student only has a small chance to be understood).

(cf. Niedderer 1982a)

3. Differences Between Teachers' and Students' MOU

The fact of fundamental differences between teachers' and students' matrices of understanding (MOUs) is well known and is supported by many empirical studies on students' alternative frameworks. I want to stress one dimension of the differences - the structural differences between science thinking and everyday-life-thinking. While science thinking aims at developing general theories for a variety of situations and problems, everyday-life-thinking is aimed at solving specific problems in special, single situations. (cf. Böhme 1981, Redeker 1978, and Schecker 1985).

The important fact seems to be that the difference in intention (aimed at general concepts - aimed at specific problem solving) has important consequences: Students use "cluster concepts" which get their sharp meaning only in a special situational context; they use formulas only as computation rules for a single case; they have in mind a special type of relation between theory and experience putting their focus on thinking in special real world representations of abstract phenomena rather than on general concept formation; they tend to look at experiments as single self-contained events rather than paradigmatic examples.

We have listed some of those differences and corresponding results of

Schecker (1985) about students' general elements of the MOU on the following page.

4. A Teaching Strategy

Our main consequence of the analysis of point 2 (see above) lies in the proposition that parts of physics teaching should be explicitely related to the students' MOU (and not the teacher's). ("Am Schüler-Vorverständnis orientierter Physikunterricht (SVU)", cf. Niedderer/Schecker 1982).

In such a teaching phase students should get the opportunity to come to own results by

- starting with an open problem situation
- asking own questions (hypotheses)
- making own suggestions for experiments, and
- working on these experiments alone (or in groups).

The students' own results afterwards are compared with similar historical theories or with the textbook. Our aim is not to replace students' theories (related to everyday-life-thinking) by the scientific theory but to arrive at a conscious knowledge of both and to learn scientific concepts by learning the differences between own everyday-life-thinking and scientific thinking.

Own results, formulated in the students' own language, are important

- to activate and bring forward students' own "tools of thinking" with respect to the problem in mind as a means to start a generative process ~~and~~
- to provide a basis for comparison with the scientific theory and hopefully, to start a more far reaching learning process by discussing the differences.

On the following page we give a model of this teaching strategy. The purpose of this model is to give some more insight into the general idea; it is not meant to bind the teacher into following this strategy in all details.

	Science	Everyday Life	Students[1]
Intention	To arrive at general theories for many different situations	To solve single problems in specific single situations	- Aim of physics is to investigate special experience with sophisticated methods
Language, Mathematics	Mathematical design using mathematics to generate a general theory ("hard science")	Qualitative description of special situations, using mathematical language only as a computation rule	- Formulas only as computation rules - Thinking in analogies, properties, purposes,
General concept structure	Concepts are defined very sharp for the general case, unique and abstractly	concepts are vague in general but sharp in the special context of a specific situation	- Students use "cluster concepts", e.g. force, as a general cause in the sense of energy or momentum or force etc.
Relation to experience	Analysing experience with respect to a general theory	Thinking is global, total and related to special situations	- Thinking in special realizations of a theoretical concept (Resistance against abstractions)
Methods (e.g. experiments)	According to Holzkamp (1968) the experiment mainly has the function of "realization" of a theory	Trial and error with respect to a specific outcome	- Physical theories come out of experiments (empiristic view) - Investigate single phenomena with sophisticated methods

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[1] Results of Schecker 1985

Concept of a Teaching Strategy Based on Students' Alternative Frameworks

General characteristics:

- Students work on their own ideas and questions (in groups or in class)
- Teacher holds back his own ideas
- Teacher does not give impulses for ideas and questions, he only provides the resources
- This teaching strategy should not cover more than half the time of a course
- The assessment of students' work is not depending on true or false, but on the inner consistency of their work.

Stage:	General Description:	Teacher Behaviour:
1. Preparation	The whole teaching process before. It can contain tools and concept preperations. It spares out a certain field of problems.	Mainly informative "normal teaching"
2. Initiation	Setting up an open problem situation with a wide spectrum of possible questions.	- Demonstrates a first experiment without explanation - Asks general questions and provides an apparatus pool
3. Performance	The process of performance comprises parts of the following sequence: formulating questions or hypotheses, planning and performing experiments, making observations, theoretical discussions, formulation of findings.	- Holds back his own point of view, especially with respect to questions, observations and explanations - Helps reservedly with technical problems - Supervises organization, gives apparatus after groups have formulated questions, asks for reports
4. Discussion of findings	The papers of students are referred to and discussed.	- Leads the discussion - Gathers results on the blackboard, using exactly the terms used by the students
5. Comparison with science	The findings of students are compared with science, either historical (small parts of original papers or teacher's presentation) or modern (presentation by the teacher or the textbook) Differences are stated and possible reasons for those differences are discussed. This leads possibly to phase 6.	- Presents the scientific theory - Selects small parts from historical papers or from a modern textbook - Discusses with single groups
6. Reflection	Students and teacher look back on the process of performance, trying to find reasons for special questions, findings and methods used and differences between their own findings and science.	- Gives information about science philosophy, particularly on the processes of development in science by examples of special theories.

(cf. Schecker 1985, p.515)

Our model is quite similar to that of Cosgrove and Osborne (Osborne/Freyberg 1985, pp.101-111). Both models stress the necessity of developing students' own views on the phenomena or concepts discussed as a basis for enabling them to learn the scientist' s view.

The "focus phase" of Cosgrove and Osborne has many similarities to our phases "initiation" and "performance", the "challenge phase" has many elements in common with our phases "discussion of findings" and "comparison with science". The differences between the two models are partly due to the fact, that we work in grades 11 to 13 (age 16 to 19). Here it is possible - according to our experience - to initiate own small research processes with students which lead to own results formulated in their own language and conceptual schemes. The process of conceptual change can be stimulated by the comparison of the elaborated own view with historical or current scientists' views. It should also contain some reflection of the performance phase using findings of the philosophy of science. The idea that learning is a generative process which starts with the cognitive tools the learner already has developed is the common theoretical basis of both models (cf. Wolze 1986).

This type of teaching has been explored by different teachers during the last 5 years in grades 11 to 13, so we have got several examples of how it works. The process can run with the whole class or students can work in groups.

It is an important finding that in step (6) students are very interested in historical information and original texts when these are connected with their own ideas, whereas we observed reluctance to deal with the history of science when we tried to start a new chapter with historical information. Our aim is to enable the teacher to understand ideas of students that originate from their own MOUs and to accept them as an important basis for teaching. Historical information will help in the phase of comparing/contrasting students' ideas with physical concepts.

5. Example 1: Teaching the Concept of "Force"

I have taught and evaluated the following unit twice in grade 11. Both times the teaching process followed more or less the structure given above.

(1) *Preparation*: The students learned the concepts of distance, time, velocity, and acceleration and their measurement in a two months course of kinetics (3 lessons a week).

(2) *Initiation*: The teacher gave a general question (an open problem)

$$a = f\ (???)$$

What does acceleration depend on ?

The students were asked to discuss and formulate questions or hypotheses and plan own experiments. They were allowed to use all apparatus available in the physics lab. They should first *write down* their questions/hypotheses and *after* having done that they were allowed to start with experiments.

Here are some of the specific questions and aims that the groups developed:

- How does acceleration of a small car on an inclined plane depend on its weight ?
- How does acceleration of a model locomotive depend on the inclination of the tracks ?
- How does the acceleration of a body depend on air resistance ? (Students fastened a sail to a small car. This car was set into motion and then braked by an electric hairdryer. Measurement was taken how acceleration depends on the power of the hairdryer and on its distance).
- How does acceleration depend on the surface condition of a road? (For this purpose different sorts of sand were put on the road).
- How does acceleration depend on the height of a car on an inclined plane ?

(3) *Performance*: The students worked in groups of two or three; they started with discussions and came to formulate questions and/or hypotheses. They thought about possibilities how to realize experiments according to their ideas and sometimes had to modify their goals to make them realizable. Mostly acceleration was determined with the sulphurpowder-method, sometimes by measuring time and distance. Special parts of the apparatus needed (hairdryer, model locomotive, sand, etc.) were provided by the teacher or brought by the students. The experiments lasted three times one and a half hour. Afterwards the groups worked out their reports.

(4) *Discussion*: Each group gave a brief report; the results were summarized on the blackboard and discussed.

(5) *Comparison with Science*: The teacher told the students that they had arrived at good and useful results (acceleration depending on motor power, power of the hairdryer, inclination of the plane, etc.). Their reports mostly contained measurement descriptions in detail and formulations of results, often using formulas which contained their *special force* ! This aim - as explained by the teacher - is similar to the work of technicians, who are often searching for a *special* formula for a *special* problem. They want to achieve a technical solution for a single situation. But physicists have a different aim: They want to elaborate a *general* theory relevant for *many* situations. To reach this aim they even invent new general concepts. One is the Newtonian concept of force *defined* by causing acceleration whenever acceleration is observed. The meaning of the formula $F = m \cdot a$ or $a = F/m$ was discussed in relation to the examples of acceleration investigated by the student groups before (meaning, measurement and computation of this general force).

(6) *Reflection*: The reflection had already started in stage (5): Physics is aimed at general results and corresponding concepts whereas technics - similar to the students' intent - is aimed at solving specific problems in single situations. Another part of the reflection was a discussion about the connection between question, experiment and theory. Some groups had "proved" hypotheses by their data although the underlying hypotheses were wrong.

Schecker in his evaluation of these lessons comes to the following result:

"The students found interesting and partially quantitative answers to their special questions. Acceleration was related to special parameters fitting with the special situations: "Power of the hairdryer", "power of the motor", "surface granulation", weight, height of inclined plane, etc. The students were very content with the process and result of their work. They had arrived at special solutions to their special questions. A viewpoint concerning the relationship between acceleration and *general* concept of force could not be found in the reports of the students.(...)

By explicitly discussing aspects of science philosophy the introduction of the Newtonian concept of force was related to fundamental structure of scientific work. In an examination some weeks later some success of this work was evident. The test contained the following question:

> "Discuss the differences between thinking in everyday life and in physics. Use examples for the formula a = F/m in your discussion. Use the contrary words: exact- unexact, general - specific, defined concepts - obvious concepts."

The answers of most students were as follows: Physicists search for general concepts, they are not so much interested in special problems. Statements of physicists are less exact in a special situation than those of technicians or of other people. In everyday life we are interested to improve our special actions. The defined concepts of physics are less illustrative than those of everyday language. Experts in physics are often hard to understand when they are explaining something.
Students from this course were eight months later the only ones in a test on general understanding of science (by Schecker) who discussed differences between physics and technics: Physics cannot have a special formula for every process, physics wants to find general rules with general formulas ! - The aim of physics is to explain general problems. The aim of technics is to find special formulas !" (Schecker 1985,p.154)

It seems plausible that this teaching strategy has started a far reaching learning process by letting students come to own results and by comparing those results systematically with the results of scientific research.

6. Example 2: Teaching the Photo Effect

In Germany quantum physics often is started by discussing the particle aspect of light, using the photo effect (photoelectrical or Hallwachs effect). We have done several small investigations around these starting point using clinical interviews with experiments (Bormann 1987) and the teaching strategy described above (v.Bötticher 1983). The teaching process described below lasted 6 to 8 lessons in grade 13:

(1) Preparation: This was the starting point of quantum physics, so no special preparation was made. The preceding courses were: mechanics; electricity; magnetism; oscillations, waves and optics; thermodynamics and sometimes relativity.

(2) Initiation: The Hallwachs effect (UV light falls onto a Zn-plate with high negative voltage) is displayed by the teacher without explanation. The electroscope is decharged.

(3) Performance: Students develop hypotheses, questions and suggestions for further experiments.
Possible hypothesis: Light (especially from an Hg-lamp) has a positive charge. Suggested experiment: Light is going through an electric field for deflection (no effect). Sometimes one or two students come to the "correct" hypothesis of electrons flowing off, but this is of no importance to most of the other students at this time.

(4) Discussion: The different theories are discussed. If possible, further experiments suggested by the students are carried out. Mostly this ends with some perplexity and doubts.

Now the process can go back to (3) and (4) again by
- new ideas from students which are accepted by the others
- information by the teacher ("there are no positive charges in light")
- distributing short selected parts of Lenard' s paper from 1902.

In any case it is good to hand out a short selected Lenard text during this phase because students mostly recognize their own conception in Lenard' resonance idea. This helps them to clarify their thinking and to come to the idea of leaving electrons (which is not at all an easy notion in the beginning). (cf. Bormann 1984, v.Bötticher 1983).
Following this it is necessary to bring in Einstein's idea of light quanta, starting with short selected parts from the introduction (heuristic viewpoint) of his paper of 1905. We have made the experience, that students often have some difficulties with this idea and that it is of help for them to discuss light propagation through vacuum. However, it is much easier and better to do this with parts of Einstein' s original paper than to try to somehow deduce the particle concept from experimental results! This is not possible and not true in a historical view !

(5) Comparison: It has to be shown that the photo effect today is sometimes calculated by using the wave concept of light (semiclassical) and sometimes calculated with light quanta. The alternating process between (2) and (3) that is repeated several times with students' ideas or historical papers, can clarify this situation and this can lead to a new concept connecting "wave" anbd "particle" models in a new model called "quant".

(6) Reflection: Students may ask why their results deviated from the textbook descriptions in the beginning of the process (- e .g. because they have difficulties to imagine free electrons in air). The teacher explains that deviations are caused by their matrix of understanding (MOU). MOUs strongly influence scientific research work, too, which can be shown by considerations of the historical development of theories about the photoeffect. (cf. Niedderer 1982c, Lenard 1902, Einstein 1905, Debeye-Sommerfeld 1913, Stüwer 1970).

7. Conclusion

I have taught 3-years' courses of physics (grades 11 to 13) employing the above described teaching strategy frequently. The students described this kind of teaching as being generally different from that of other teachers, not only in phases when I used the new strategy. They said that in the beginning they had been afraid the course would not cover a wide enough range of subjects to be properly preparated for the "Abitur" (the final high school exam in Germany), but when they had afterwards looked into the referring textbook chapters they had been able to understand their contents.

I think, this is the hope of many teaching strategies which in Germany had their famous protagonist in Martin Wagenschein: To reduce the variety of subjects and to come to a deeper understanding of physics. This becomes possible, if teachers have a better understanding of their students - by knowledge of the results about students' alternative frameworks - and if students better understand physics gaining insight into the philosophy of science.

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Changing students' explanatory frameworks concerning the nature of light using real time computer analysis of laboratory experiments and computerized explanatory simulations of e.m. Radiation.

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Introduction

In this study learning is seen as a process of interaction between knowledge already existing in the mind of the student and new knowledge. In this, the study is based upon Kelly's (Kelly 1965) Personal Constructs theory in which man is seen as a scientist who explains and predicts future events by building tentative models and evaluating these models by means of personal criteria. In using this approach we assume that students hold conceptual frameworks prior to the beginning of formal learning.

Most of the studies carried out in the field of student conceptual frameworks (Champagne, Klopfer and Guston, 1983; Gilbert Osborne & Fensham, 1983; Gilbert Watts , 1983; Driver and Beverley, 1986; DiSessa, 1985; Hewson and Hewson, 1981) have focussed mainly upon the identification of concepts held by students, and less upon the roots of those concepts or on the process of change in the conceptual frameworks held by students. Our main interest here is in the process of change

taking place as students attempt to explain light related phenomena.

Interaction between prescience conceptual frameworks and frameworks introduced in learning do not necessarily build the hoped for conceptual frameworks. A pilot study carried out in order to examine concepts held by physics students, supports this assumption with respect to students' misconceptions concerning the nature of light.

In our attempts to follow the process of change, we found it necessary to build a series of learning situations rooted in theories of conceptual change. Our research program comprised three stages:

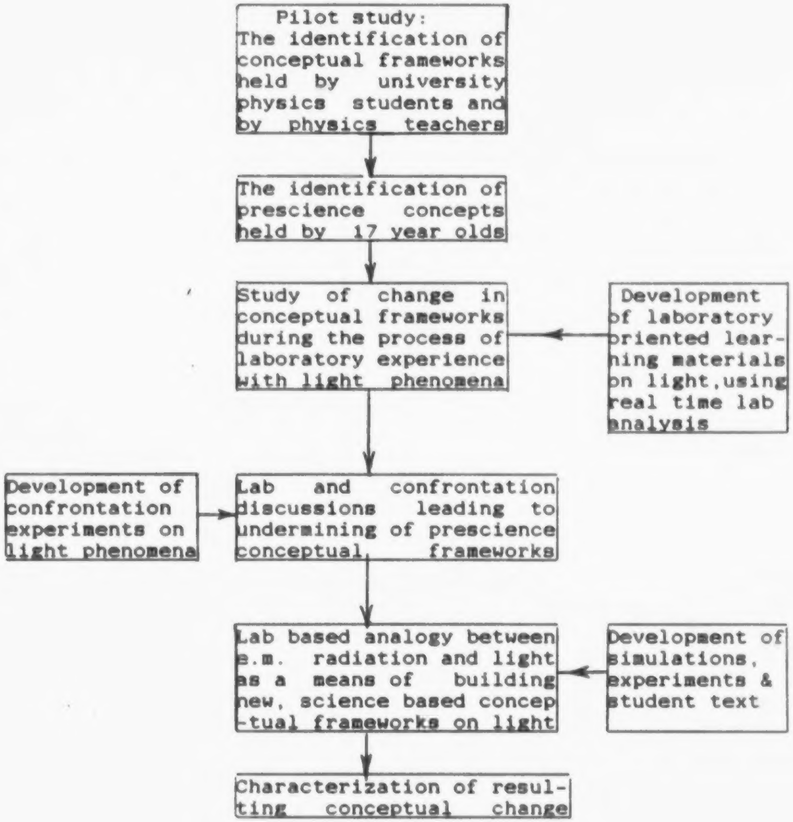
(1) Identification and analysis of students' prescience conceptual frameworks on light, based upon discussion about demonstrations of light phenomena.

(2) Development and implementation of a series of laboratory learning situations in which experimental phenomena examined by the student are accompanied by real time computer based analysis.

(3) Identification and analysis of change and of the process of change in students' conceptual frameworks. The analysis of the process of change was carried out in two different situations. The first, built around

a series of experiments, which, while designed as good learning experiences, took no account of student's prescience concepts. The second, carried out after a process of undermining prescience concepts, is built around analogies drawn between phenomena familiar to the students and light phenomena.

The Structure of the study


Pilot study: The identification of conceptual frameworks held by university physics students and by physics teachers
The identification of prescience concepts held by 17 year olds
Study of change in conceptual frameworks during the process of laboratory experience with light phenomena
Development of laboratory oriented learning materials on light, using real time lab analysis
Development of confrontation experiments on light phenomena
Lab and confrontation discussions leading to undermining of prescience conceptual frameworks
Lab based analogy between e.m. radiation and light as a means of building new, science based concep-tual frameworks on light
Development of simulations, experiments & student text
Characterization of resulting conceptual change

We now report very briefly on the conceptual frameworks found current amongst the 17 year old students of the research group, and go on to the main focus of this report. This is the process of change in conceptual frameworks brought about by: the real time analysis of experiments; the undermining of naive physics; the use of computer simulations in the establishment of an explanatory model; and the use of analogy as a trigger for the reconstruction of students' explanatory frameworks on light.

Naive concepts of light

The first stage of the study uses interviews concerning physical phenomena in order to identify prescience conceptual frameworks held by eleventh grade students majoring in electronics in technological high school. It was found that these students held conceptual frameworks which could be classified with reference to five topics concerning light: sources of light; changes in light intensity; the nature of light; light and sight; and light and colors. Each of these topics can again be classified according to the way in which students understand them.
These second stage categories are:

1. Light sources are seen as hot bodies, or as chemical reactions, or as fire.

2. Changes in light intensity are seen as : a slow fall in intensity up to a certain limit beyond which the light vanishes; light as latent in objects (some kind of conservation law which explains why darkness doesn't follow immediately upon sunset); the rate of change in light intensity is a function of its color so that blue light doesn't travel as far as yellow light; the rate of change in light intensity depends on the velocity of light which in turn depends on the power of the source, so that a stronger source is visible from a greater distance.

3. Light is seen as particles, or waves, or as a combination of rays and a "sea" of light, or as heat.

4. Sight is possible when light is reflected from bodies or whenever light "fills" the space or the air around. (Few students grasp the need for light to enter the eye as a condition for seeing).

5. Light of a given color is conceived as material of that color. This apparently leads to the assumption that the illumination of a blue object by red light makes the object seem violet,(whereas in reality it would seem to be black), just as a mixture of red and blue paint produces violet.

It was found that the most prevalent and dominant concept held by these students was the equating of light with matter. This concept appears to underlie and direct most of the student explanatory frameworks on light. This may be seen in the following examples of students' beliefs: Light is viewed as the emission of material particles from hot bodies which lose weight as they emit the light; Light particles make the Crookes radiometer revolve just as if they were small billiard balls; They heat the media through which they pass by friction, lose speed and thus lose intensity; Sight is made possible by light which fills space just as air fills space; Mixing light beams of different colors is equated with the mixing of materials with these different colors.

Real time analysis of experiments and Simulations:

The laboratory setup

The basic equipment includes:

1. an IBM PC;
2. an analogical - digital converter (A <--> D);
3. a light sensor; a temperature sensor;
4. an optical bench along which the sensors can be moved;

5. a step motor controlled from the PC keyboard to move the sensors along the bench or to rotate them at a selected constant velocity;
6. a set of light sources; and
7. a 3cm micro wave kit.

Figure 1 shows one experiment as an example. A light sensor (3), mounted on a cart, is connected to the A-D converter (2). The step motor (5), controlled by the student from the PC keyboard, moves the cart at a fixed selected velocity towards a fixed point source of light (6). The light intensity measured by the sensor changes. This changes the analog signals from sensor to A-D converter which converts them to digital signals transmitted to the computer. The computer monitor displays a real time graph of light intensity as a function of time. Figure 2 is a computer print out of such a graph. Figure 3 is another computer print out for an interference pattern.

Three kinds of laboratory experiences are provided. These are experiments with light, as exemplified above, experiments with 3cm e.m. micro waves, and wave simulations.

The first deals with: intensity and distance; intensity and direction; the light field concept; absorbtion and thickness of medium; absorbtion and color of medium; absorbtion and temperature. These experiments are designed for the study of change in students' conceptual frameworks on light. As the

study progressed it was found that students' conceptual frameworks were enriched but remained basically unchanged. Three additional experiments, on diffraction, interference and polarization served to undermine firmly founded naive concepts and thus provide the necessary conditions for their reconstruction.

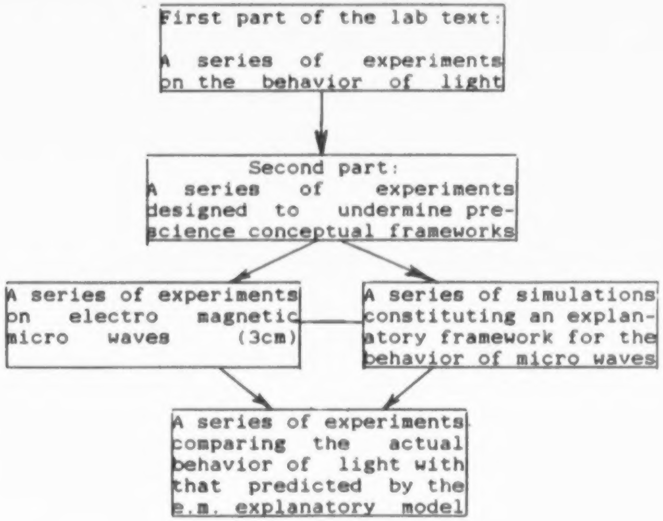
The second kind of laboratory experience deals with: propagation of an electro magnetic field in space; direction of propagation and reception; reflection and transmission; polarization and revolution of the plane of polarization; diffraction and interference.

The third presents a series of computer simulations on: propagation of an electro magnetic field; diffraction; and two slit interference; with the aim of building an explanatory model for light.

The experiments with e.m. micro waves and the computer simulations, together constitute a base for the construction of analogies between micro waves and light. These analogies in turn provide the student with the means for the development of new explanatory frameworks.

The following chart describes the general structure of the experimental setup and the relationships among the three kinds of laboratory experiences.

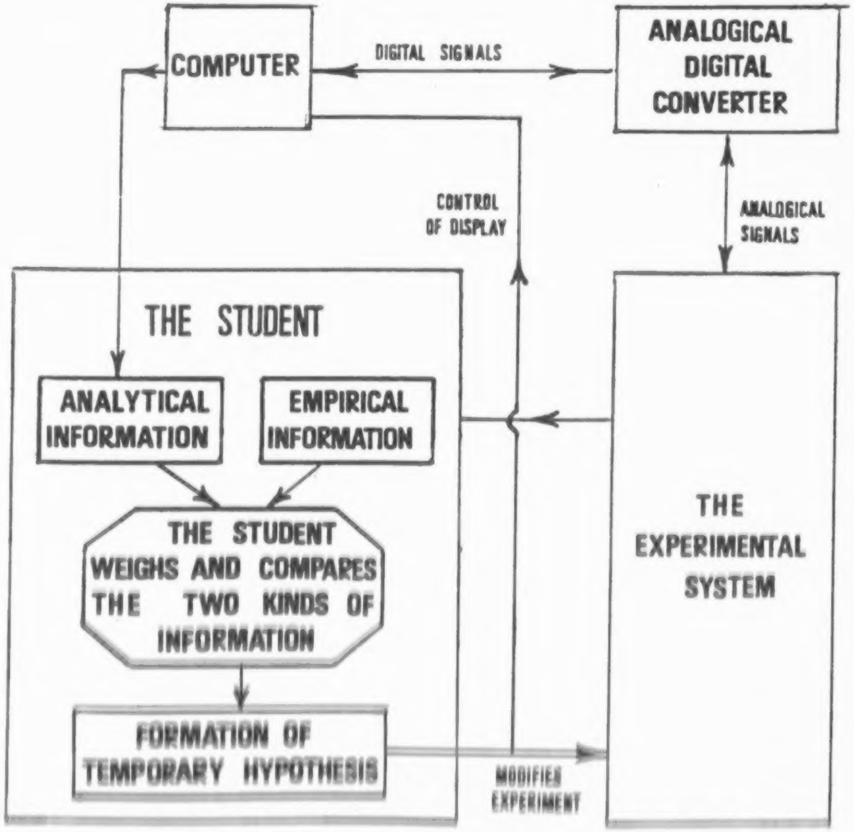
Structure of the experimental setup:


First part of the lab text:
A series of experiments on the behavior of light
Second part:
A series of experiments designed to undermine pre-science conceptual frameworks
A series of experiments on electro magnetic micro waves (3cm)
A series of simulations constituting an explanatory framework for the behavior of micro waves
A series of experiments comparing the actual behavior of light with that predicted by the e.m. explanatory model

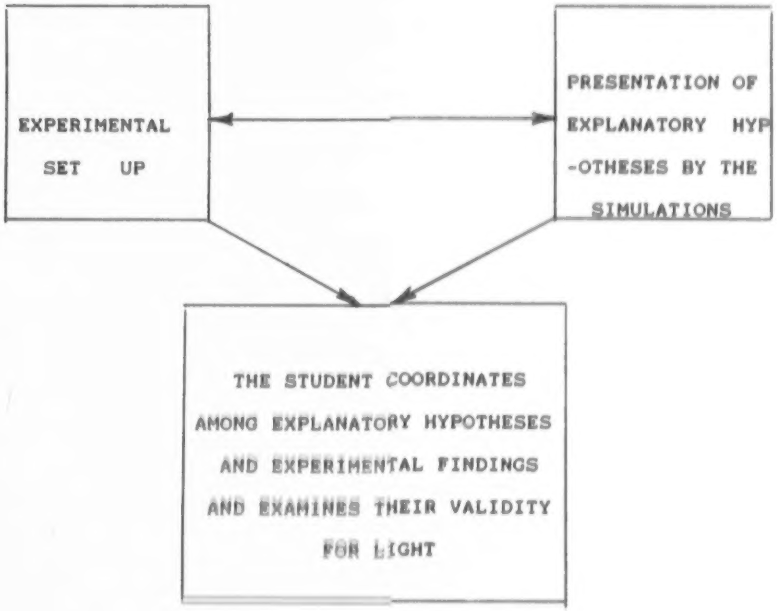
The use of the computer as a real time analytical device

The student is provided simultaneously with empirical information from the physical system and analytical information from the computer. This two fold presentation of information increases what Posner et al (1982) call the intelligibility of the physical concepts involved. On the basis of the continuous simultaneous juxtaposition of both kinds of information the student is able to build, modify and rebuild explanatory hypotheses. In this resides the power of the system as an agent for change of students' conceptual frameworks, since it provides for the immediate testing of ideas against experience. Using Kelly's term (1965) this is the construction and testing of personal theory. Unlike analysis in the traditional school laboratory experiment, here analysis becomes an integral component of the experiment.

THE USE OF THE COMPUTER AS A REAL TIME ANALYTICAL DEVICE


COMPUTER
DIGITAL SIGNALS
ANALOGICAL DIGITAL CONVERTER
CONTROL OF DISPLAY
ANALOGICAL SIGNALS
THE STUDENT
ANALYTICAL INFORMATION
EMPIRICAL INFORMATION
THE STUDENT WEIGHS AND COMPARES THE TWO KINDS OF INFORMATION
FORMATION OF TEMPORARY HYPOTHESIS
MODIFIES EXPERIMENT
THE EXPERIMENTAL SYSTEM

We use the computer simulations as tools to present hypotheses for the explanation of phenomena. The combination of experiments and simulations is intended, at this stage, to lead the student towards the development of an explanatory model for e.m. radiation. By repeated comparison of experimental results with explanatory simulations, the student is encouraged to test the validity of his or her personal model. In the final stage of the laboratory work the student tests the validity of this model for light.


EXPERIMENTAL SET UP
PRESENTATION OF EXPLANATORY HYP-OTHESES BY THE SIMULATIONS
THE STUDENT COORDINATES AMONG EXPLANATORY HYPOTHESES AND EXPERIMENTAL FINDINGS AND EXAMINES THEIR VALIDITY FOR LIGHT

As the student goes through the experiments on light he or she finds that whereas some light phenomena can be explained on the basis of personal experience, this becomes increasingly difficult or even impossible for diffraction, interference and polarization. The behavior of micro waves, viewed by the naive student as having nothing in common with light, is then seen to parallel the behavior of light. Finally the e.m. wave simulations are used in an attempt to build a combined explanatory framework for the behavior of light and e.m. waves.

Changes in students' conceptual frameworks resulting from experiments with light

Change in conceptual frameworks is examined during the process of experimentation with light using real time analysis in the laboratory set up described above.

Students attended eight meetings of ninety minutes each.
During laboratory work, each student was interviewed on the experimental processes and outcomes. The interviews were recorded on tape and extensive notes taken.
It was found that initial conceptual frameworks remained almost unchanged. New concepts were added but these did not change basic perceptions.

For example, in one experiment a light source heated two identical glass containers of black coffee and weak coffee. Students internalized the knowledge that the rise in temperature of a medium through which light passes is a function of its color. However their explanations of this phenomenon remained rooted in their prescience beliefs concerning the nature of light. Heat, they explained, is created by friction between light particles and the particles of the medium. As the coffee (the medium) becomes darker, it becomes denser, friction increases and the temperature rises.

In one interview a student considered the problem of red light passing through a blue filter. He claimed that the red light would emerge as blue light, and when asked to check this experimentally he found his claim was false. He suggested that the red light and the blue filter were both too dark so that the light passing through seemed dark. Clearly his claim is based upon the perception of red light as a red material that can be colored by a filter: the light particles take the color of the filter.

The learning process appears to be that of assimilation of new items of knowledge by the previously held framework. The question arises, is it possible to accomodate the existing conceptual framework to that desired by the teacher?

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There is general agreement, following Dewey (1910), that change can take place in conceptual frameworks when students are made aware of the inadequacy of their existing frameworks. Such awareness may lead to cognitive dissonance (Festinger, 1957) or conceptual conflict (Berlyne, 1965), giving rise to a need to reduce conflict between the opposing cognitions. Berlyne speaks of epistemic curiosity as the motivation for a move towards the reduction of such conflict. Nussbaum (1982) claims that epistemic curiosity arising out of conceptual conflict may lead to change, or accomodation, of conceptual frameworks.

Accordingly, laboratory situations were arranged to demonstrate phenomena which students could not explain on the basis of their personal naive physical concepts. We have already noted that these were experiments on the passage of light around obstacles, through single slits, double slits, and polarizers. Not only were students required to cope with the experiments and their outcomes. They were confronted with questions put by the interviewer which forced the admission of inability to explain the observed phenomena.

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Lab based analogy for the construction of conceptual frameworks

Having set the appropriate conditions, the aim now was to present viable alternative explanatory frameworks. The final stage of the study deals with the establishment of new conceptual frameworks. Analogies were drawn between the qualities of electromagnetic micro waves and the qualities of light. In accordance with the approach of Gentner and Gentner (1981) this part of the study was carried out as follows:

1. An experimental investigation of e.m. micro waves.
2. A study of the validity of explanatory hypotheses concerning experimental outcomes presented by means of computer simulations.
3. The construction of explanations concerning the qualities of electromagnetic micro waves.
4. The examination of the validity of these explanations with respect to light.

At this stage of the study all of the students explained light as an e.m. phenomenon. Concerning the application of this explanation to the behavior of light, it was found that most of the students had changed their approaches to the nature of light sources, the nature of light and changes in light intensity. Fewer students changed their approaches to sight, and even fewer changed their approaches to the nature of color in light. This suggests that the learning process described has potential for success in bringing about change in conceptual frameworks. It also points to possible ways for improving the presentation of phenomena and the examination of the validity of prescience concepts which act counter to the learning of new concepts.

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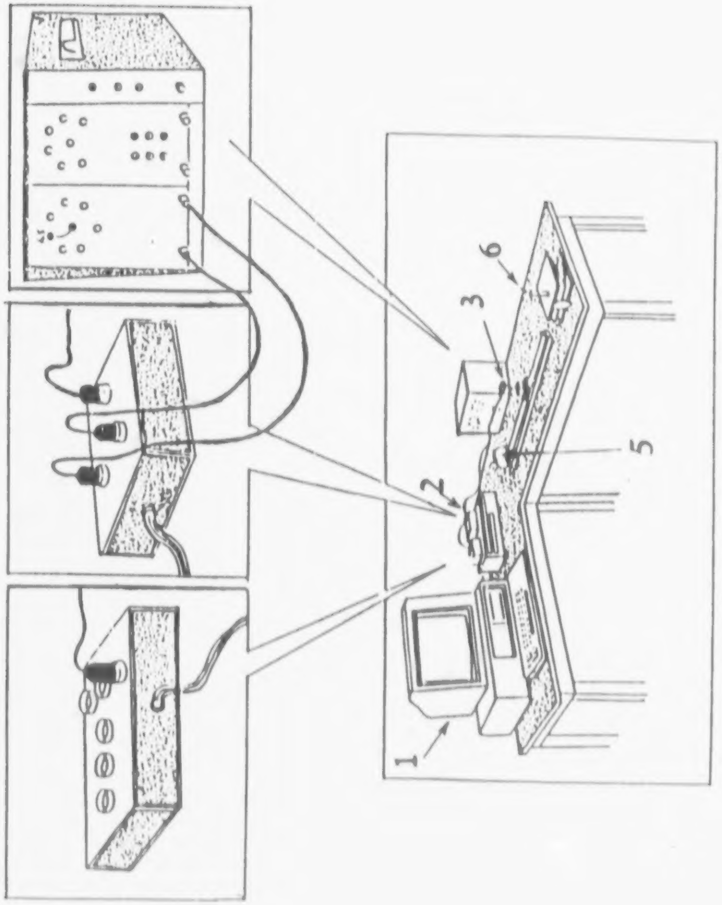
Figure no. 1: **THE EXPERIMENTAL SET UP:**



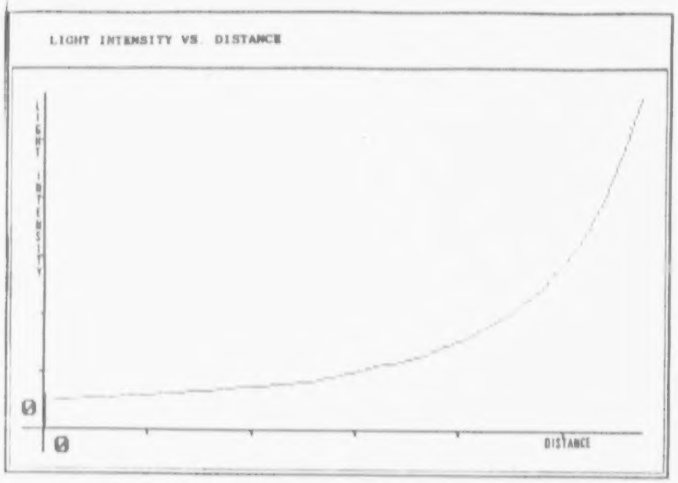


Figure no. 2: Change Of Light Intensity With Distance

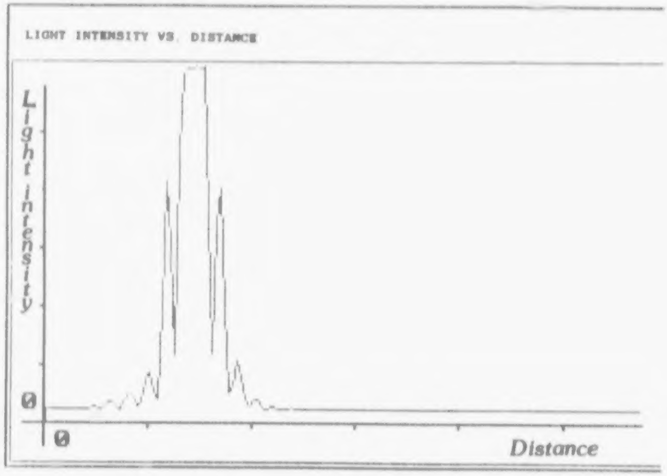


Figure no. 3 : Change Of Light Intensity With Distance

Teachers-as-learners: Images from the Past and Implications of a (Generative) Constructivist Perspective for the Future

Meg Richardson, Cornell University

There is currently a great deal of research which is focused on how children learn science concepts. Based on this growing body of knowledge about how children learn, there are programs designed with teaching strategies that encourage conceptual change in learners. Examination of related teacher education and development programs shows there is a need for further delineation of conceptual change strategies for use *in the teaching of teachers*. This may, I think, be best accomplished only with a better understanding of the "meanings and concepts" (see Wittrock quote, below) of teachers' practice. It is my argument in this paper that a "generative" learning theory offers help in this consideration of teacher-as-learner.

My particular concern is with the in-service elementary teacher-as-learner. There is an increasing demand that more and better science be taught in the elementary school. Since elementary teachers have traditionally not been trained well in science (see Weiss, 1978), there is a growing realization that the elementary teachers themselves need to be considered as science learners. In addition, since conceptual change strategies are not familiar to many teachers, there is a further need to help teachers change the ways they teach. In the past, it has been shown that getting teachers to change the way they teach is most difficult to do if the realities of the teachers' experience are not taken into account (see Ponder and Doyle, Olson 1980, 1981).

In the first section of this paper, I will give an account of models of teacher-as-learner as they appear in the educational research literature in process-product studies, and studies on curriculum innovation and implementation. I will look especially at recent research which focuses on the teachers and conceptual change science teaching. Some but not all of the models of teacher-as-learner are implicit in literature which has as its primary commitment the study of the relationship between teacher behaviors and student outcomes, or the introduction of an innovative program. However, I believe that it is important to tease out the concept of "teacher-as-learner" as it has changed and is evolving over time within the research/innovation introduction context because it may offer useful insight for the re-examination of in-service teacher development programs.

In the second and third parts of the paper, I will examine what a "generative" learning model is, and what it may suggest for the teaching of teachers.

Images of Teacher-As-Learner.

In the past, teachers have been studied - most often in relation to desirable student outcomes (process-product and teacher effectiveness research), and also, in relation to curricular innovations. In each case, the teacher is narrowly conceived as a variable in a linear equation (curriculum + teacher (teaching) = positive student outcome or successful introduction of innovation), and in each case the teacher has been perceived to be problematic; i.e., why the equation doesn't work out. The teachers were studied but their beliefs, thoughts , and feelings were not the primary data gathered. The goal of the process-product research was to discover the right set of teacher behaviors so that teachers could be trained and positive student outcomes ensured. The implicit view of the teacher-as-learner in this research was that she should be a passive recipient of whatever knowledge had been discovered by observations in the classroom. To the extent that this did not occur, the image of teacher-as-learner in this research paradigm may be said to have been the uncooperative, unmotivated kid in the back row ("stone-age obstructionist"- Ponder and Doyle). Currently, in direct instruction, which may be said to be the current result of the process-product research, teachers receive training in how to teach, and for certain subjects the teacher training effects positive student outcomes. The right way to teach is seen as descending from above to teachers.

For many, the narrow definition of teaching and therefore teacher-as-learner derived from the process-product literature has proved inadequate as a description of the complexities of teaching practice and as a tool for the changing of practice. In the process-product research, there was a "flawed conception of how teaching can influence learning" stemming from "a limited view of the role of the teacher and of teaching in the instruction-learning process" (Shavelson, Webb, and Burstein, pp 51-52). Research on teacher thinking, which might be expected to have come up with a different definition of teaching, has been tied by its association to the process product research; its task has been to explain why teachers do what they do in order to understand the lack of a powerful relationship between teacher behavior and student outcome ("puzzling and contradictory findings of the process-product research on teaching and curriculum change implementation research"; Clark and Peterson, p 292).

Teachers have proved to be a bothersome intervening variable in the introduction of innovation; the teacher-as-learner didn't learn well, and so the innovations didn't work. Attempts to introduce curriculum which required teachers to change how they taught often failed as soon as teachers were left to interpret novel instructions themselves. Often what was innovative became "translated" (Olson's term) into the familiar. This was the fate of many of the innovative curricula of the 60s and 70s (eg, Weiss, Stake and Easley). Olson and Ponder and Doyle are observers and commentators on this phenomenon of curriculum translation. Olson examines this phenomenon in depth in his studies of eight secondary teachers in England responding to an innovative science curriculum (Schools Council Integrated

Science Project) (Olson, 1981). In Olson's study, teachers acted to reduce the ambiguity of a new situation in which they were supposed to teach with "low teacher influence" in such a way that the end result was similar to their usual "high influence" teaching. The fate of innovations has also been studied by Walter Doyle (Ponder and Doyle, ?). Innovations perceived by teachers to be "impractical" were incongruent with the norm of classroom practice and incongruent with the teacher's familiar role. Innovations also have a high degree of risk associated with them, which reduces the chance that a teacher may adopt them. It is easy to see why teachers may have been regarded as "stone-age obstructionists" (Ponder and Doyle, p 9) by curriculum innovators.

In the recent past, "innovators" were curriculum designers and/or experts in the field of study. The experts designed curriculum based on concepts of importance to the methodologies or content of the field. In elementary science, SAPA, ESS and SCIIS, are well known examples. These are among the curricula which did not finally, "translate" well into the classroom, and teachers came to be studied in relation to the failure of these curricula.

Before the classroom itself became the focus of study, the roles of "innovator", "researcher" and "teacher educator" were clearly and separately defined. However, in the study of how and why the failures occurred, "innovators" have rightly gone into the classroom first as educational researchers, and more recently as teacher educators (for example, Smith and Anderson, et al at IRT, and Smith and Neale at the University of Delaware, Osborne, et al at Waikato, and Driver et al at Leeds). Innovators became researchers when it was perceived to be important to study teaching in the field at all, and currently are taking on the role of teacher educators as well. When the focus is on in-service secondary teachers, another role has evolved for the innovator/researcher/educator- that of collaborator. This has been the case in the CLIS (Children's Learning in Science) Project at Leeds. This development is not perceived as clearly in projects where elementary teachers are the focus of change/development efforts. However, the introduction of innovative classroom practice or content, the study of teachers, and the teaching of teachers are more and more considered important aspects of the one process, implementation of change.

Currently, elementary teachers are being studied not only in relation to their teaching of science, but also for the degree to which their normal practice may be conducive to teaching for conceptual change in their students. Conceptual change teaching requires that students be given the experiences and information necessary for them to "construct" from their own incomplete and/or incorrect ideas about the world around them the concepts of the disciplines of science (Posner, et al, 1982). Conceptual change teaching requires that the teacher have knowledge and concepts of the discipline, be aware of the relevant (incorrect and correct) concepts students come to school with, know how to teach so that children will change their ideas, and have a conceptual change approach to the teaching of science. All of these present formidible obstacles for elementary teachers in learning and doing, and for innovators in teaching teachers.

That teachers may have a hard time learning the science and conceptual change strategies is recorded in the work of Smith, Anderson, and their group at Michigan State. Their findings have been that "teachers' views of teaching and learning stayed fairly stable over the course of the project; they were not strongly affected by either the workshops or our teaching materials" (Smith, Anderson et al, (a) p 5). Anderson, in the conclusion of his report to BSCS: "We have found that not only most teachers lack the specific knowledge needed to teach for conceptual change, but also that many teachers have beliefs about teaching and learning that are incompatible with those described in this paper" (Anderson, 1987, p 46). The difficulties involved in teaching elementary teachers the several different kinds of knowledge necessary for conceptual change science teaching at the elementary level are amply recorded in the work of the Smith and Anderson group at Michigan State, and and also in the research/ teaching of teachers being carried on at the University of Delaware by Deborah Smith and Daniel Neale.

While Deborah Smith has made use of conceptual change strategies *in the teaching of teachers* and in her

research/teaching, there is little doubt that the process of teaching teachers so that they change their teaching is a very time intensive procedure. This is borne out by complementary work being done in the field of curriculum implementation (for example, Hord and Loucks). In Smith's work, teachers are supported and encouraged by her, and the teacher-as-learner (of science and conceptual change teaching strategies) becomes indeed a collaborator in a shared enterprise. Her interactions with in-service elementary teachers mirrors work now being done by Anderson of Michigan State with pre-service teachers. In her work with teachers, Smith "models" conceptual change teaching, "coaches" with teachers (each coaches the other), and then allows teachers to continue to teach on their own ("fades"). Smith has had some good short term results as teachers have begun to feel competent and their attitudes toward science have improved. However, as mentioned above, the process she is using is a slow one, and is very content specific. This leads to questions about the feasibility of such an approach in the teaching of in-service teachers, and must be explored in further research on constructivist approaches to learning.

In addition to well documented lack of science training and experience (Weiss, Stake and Easley, Hounsell), there is the (usually negative) affective side of elementary teachers' interactions with science. This is certainly an important "meaning" aspect of teachers' interactions with science and science teaching and Smith and Neale report on some pertinent examples. A teacher has just heard that as part of her summer science workshop she is to learn some physical science (as opposed to biological science): "Well you have ruined my day. I hate you; why did you say that?" and, thoughts on science in general: "Science always has sort of a special feel when you hear the word-- 'Oh, that's for smart people.' and you are an education major and you will stick with reading and math and that kind of thing." (Smith and Neale, p 20). With teachers who feel this way about science, care has to be taken to help them undertake the task of learning science.

In the work of Driver, et al at the University of Leeds there is a carefully thought-out emphasis on teacher as collaborator. Here again, however, it has been found that even where teachers have been involved in curriculum development focused on conceptual change teaching, time must be spent in order to help teachers change how they teach science (Johnson, 1987). The implications from all of these studies/attempts at innovation is that there is a tremendous amount of work to be done if elementary teachers are to teach science so that conceptual change in their students will be the result.

There are a number of pre-service programs designed to introduce pre-service teachers to conceptual change teaching. Pre-service teachers are taught themselves in ways which encourage reflection and conceptual change. Conceptual change strategies and a constructivist approach to learning have been built into pre-service science education programs at the University of Georgia, University of British Columbia, University of Tasmania, Michigan State, and are being built into the new program here at Cornell. Included in many of these are opportunities for pre-service teachers to identify and share their own ideas about teaching and learning which they have developed over many hours as students in school, and opportunities to observe, experience, and discuss teaching practice. At British Columbia, they are developing "exemplars"- video taped examples of different problems of practice- for pre-service teachers to analyze, try out solutions for, and discuss with peers and teacher educators. Interactions between supervising teacher and student teacher in the practicums of these programs are often meant to include "modeling, coaching, fading" (Anderson, at Michigan State) or "the follow me", "joint experimentation", and "hall of mirrors" model (Erickson, University of British Columbia). While these may offer valuable insight into new ways to interact with in-service teachers (perhaps even with the supervising teachers) as well as with pre-service teachers, this seems to be an area that still needs more attention. Continued exploration of how supervising teachers may best be included in the design and continuing operation of pre-service programs, will no doubt, provide useful results for the development of in-service teachers, along the lines I am going to suggest in a moment.

The research/innovation attempts above are examples of the ways in which elementary teachers are currently being researched/taught by educators committed to a conceptual change approach to the teaching of children. There have been great strides made in coming to understand and categorize the kinds of knowledge which are of *most importance* to the teaching of conceptual change science. In itself, this advance in understanding has highlighted the complexity of teaching of any sort at both the lementary and secondary levels. To the extent that the goal of teacher science education would be for elementary teachers to acquire the knowledge and skills necessary to teach conceptual change science, component parts of such a program are now much more clearly delineated than has been true in the past. Unfortunately, along with the clarity has come an increasingly daunting prospect in regard to the enormity of the task. The question of whether or not elementary teachers can be taught *all the science that needs to be taught* to achieve competent conceptual change teaching in even one area of science is an open one, given the other demands on their time in training and on their time as practicing teachers, as that job is currently defined. Examination of these programs shows that while conceptual change strategies for the teaching of children is their focus, there is a need for further delineation of conceptual change strategies for use *in the teaching of teachers*.

These programs have initiated an expansion of the role of the innovator in change efforts; the study and teaching of teachers is becoming an accepted and even explicit part of curriculum development. Along with the closer and more complex association of innovator and teacher has come increased knowledge about the complexities of classroom life, and a growing understanding of teachers' thoughts, beliefs and attitudes. The result has been an increasing respect for the teacher and what she does. However, because of the difficulties of getting teachers to change what and how they teach, the teacher-as-learner is still often perceived by innovator/researchers to be the problem instead of part of the solution. A tendency to see teachers in this way has the possibility of being stronger with elementary teachers since in order to teach conceptual change science they not only have to change the way they teach, but they also have to learn some science. Because of this it may be more difficult for innovator/researchers to see themselves as collaborators and colleagues with elementary teachers than with secondary teachers. It is my argument that even more than is the case presently, consideration by researcher/innovators of elementary teachers-as-learners of conceptual change teaching strategies and of science, has to focus on an understanding of their teaching strengths and expertise. Innovators/researchers are not always speaking to teachers in a language that they can understand, one that takes full account of the "meanings and concepts" (see Wittrock quote, below) of the teacher's world, perhaps even aspects of that world that seem not to relate directly to the learning and teaching of science ("The innovator must learn the teachers' language if he is to communicate with them and he must talk with teachers in order to learn how their language can be used to evolve ways to express the new ideas he wishes to advance." (Olson, 1981, p 272)).

Ponder and Doyle point out that programs to train "teachers either to use more rational deliberation procedures or to acquire more refined implementation skills often discount the potential impact of *the larger ecology* on teacher attitudes and behavior" (Ponder and Doyle, ?, p 13), and thinking. As John Zahorik has written, "the major problem with research on teaching *[and, one might add, attempts at educational innovation)* is that it has ignored the teaching preferences of teachers... experienced teachers have beliefs and convictions about what is right and... experiential knowledge of what works.". (Parenthesis, italics mine) Coming to understand the "meanings and concepts" of experienced teachers about their practice is, I think, a responsibility of those who would enable teachers to change the way they teach any subject. This may require "a much closer contact between teachers and innovators at the level of ideas" (Olson, 292) Olson emphasizes that the contact must be made *in the teacher's language*. This process with elementary teachers and science teaching has been initiated by the work of Smith, Anderson, et al, and Smith and Neale and others. However, more remains to be done: (again) "the innovator must learn the teachers' language if he is to communicate with them and he must talk with teachers in order to learn how their language can be used to evolve ways to express the new ideas he wishes to advance."(Olson, ibid).

Constructivist, Generative Learning Models:

In this section, I am going to describe a "generative" learning model as an example of a "constructivist" approach to learning. Although I am going to describe the "generative" learning model of Wittrock as I understand it, the major point I want to make here is that the "meanings and concepts" and needs of the learner should start off and remain the center of concern for the educator. While this is a possible emphasis in any "constructivist" approach to learning, the "generative" learning model seems to focus strongly on and maintain a focus on the learner which continues to be useful in the determination of what will be taught and how it will be taught. The emphasis on the learner's "meanings and concepts" is important for researcher/innovators to maintain as they study/teach teachers, so that they may better understand and speak the teachers' own language, as suggested in the Olson quote above.

A strong focus on the "meanings and concepts" of the learner is of particular importance when adults are the learners, and their whole-hearted cooperation is necessary for learning to occur. That a generative learning model has this emphasis is borne out, I believe, by comparison of the wording of the following statements, paraphrased by Osborne and Freyburg:

> "find what meanings and concepts that the learner has generated already from his or her background, attitudes, abilities and experiences and determine ways so the learner will generate new meanings and concepts that will be useful to him or her." (Osborne and Freyburg, p 82, after Wittrock, 1974).

> "find the prior concepts of the learner and determine the necessary links between what is to be taught to what the learner already knows" (Osborne and Freyburg, p 82, after Ausubel, 1968, 1978),

> "find the alternative viewpoints possessed by the child and provide material in such a way so as to encourage the child to reconsider or modify these viewpoints." (Osborne and Freyburg, p 82, after Driver, 1980).

In the latter two, it is explicit that the learner is to learn "what is to be taught" or to "reconsider or modify" his/her original viewpoint. In a generative learning model, what is to be taught should spring only from what prior meanings and concepts have been generated already by the learner, and the result should be " new meanings and concepts that will be useful to him or her". (Underlining mine) As further evidence that the intention in a generative learning model is that the student is of continuing and central importance, Osborne and Freyburg in their work based on Wittrock, point to the importance for teachers of a "student dominance" approach to the planning of science lessons.

There are two questions related to "student dominance" which must be taken into account in any constructivist pedagogy. First is which prior meanings and concepts of the students are allowed to be considered relevant. The second is a question of the extent to which these should be taken into account in planning and teaching. These need to be addressed in relation to the teaching of in-service teachers as well as in relation to the teaching of children. Pines and West focus on this problem inherent in constructivist approaches in general: "Should science education be concerned about imposing the downward growing vine: formal school science? A case can be made that school science should be concerned with nurturing the upward growing vine: spontaneous acquired belief systems" (Pines and West, p 600). The strength of a generative learning model is that it does focus on the "upward growing vine". A generative learning model requires of an educator knowledge of a broad field of relevant "meanings and concepts", requires that it be used extensively to plan and teach.

It is my contention that so far, the relevant "meanings and concepts" for the teaching of in-service elementary teachers have been construed narrowly. A broader understanding of what it is that is important to elementary teachers about their teaching has, I think, a great deal to contribute to the field of teacher education/development. However, as suggested above, it has not yet fully emerged to inform teacher development strategies. This is an area for further research. What follows is an attempt to outline some of the elements of a "generative" approach to the teaching of in-service elementary teachers using ideas from writings about generative learning and from recent research/innovation programs and pre-service teacher education programs focused on the teaching of science.

The Beginnings: A "Generative" Approach to the Teaching of In-service Elementary Teachers

A generative learning model has something to say about *what* should be taught as well as *how* it should be taught, and this should be as true in the consideration of teachers-as-learners as it would be with student learners. A generative learning model will promote the continuing evolution of roles of the innovator/researcher/teacher educator and of the teacher-as-learner (from passive recipient to an equal collaborator). Osborne and Wittrock outline a hypothetical program for teaching elementary teachers science. This program is based on the knowledge about elementary teachers that they are interested in children (so making use of the "meanings and concepts" of teachers in the program design). Osborne and Wittrock would use this interest as a way to intrigue teachers with the idea of children's science-- children's preconceptions about science which affect their school science learning-- so that the teachers themselves may become science learners. Osborne and Wittrock's program would include:

> "(1) interviews with children so that participants better appreciate children's ideas and develop questioning and listening skills.
>
> (2) peer group discussions to clarify participants' ideas with respect to each other, scientists and children.
>
> (3) the design of experiments to test the predictions which follow from children's ideas.
>
> (4) the historical study of critical evidence which led to the restructuring of specific scientific knowledge, and
>
> (5) the consideration of possible reasons why children hold a specific view, or a meaning for a specific word, that is different to scientists' ideas." (Osborne and Wittrock, p 502)

In this program, Osborne and Wittrock address many of the kinds of knowledge needed for the teaching of conceptual change science *to some extent*. However, they do not address problems having to do with beliefs about how science should be taught, nor conflicts with normal teaching patterns (part of pedagogical content knowledge), nor issues related to the feelings of teacher-learners. Deborah Smith has taken some of this into account in the way that she works with teachers. The process is slow, and at the beginning is really focused on getting the teachers to feel comfortable with the researcher/innovator and with eachother as they learn in a subject they have always found opaque and intimidating, and where they are being asked to change the way they teach.

Osborne and Wittrock also go no further in exploring teachers' other interests as ways to attract them to science learning, or as possible ways to teach elementary science. In the latter case, I am thinking of elementary teachers' tendency to feel more comfortable with the life sciences and with natural history, than with the physical sciences. Another way to make use of teachers' interests might be the integration of science and social studies. In a recent case study completed as a pilot for my dissertation research, a teacher who loathed teaching science was also interested greatly in social studies and in the part of science and technology in causing and solving large scale social problems (although she admitted this with some surprise that this showed that she was interested in some aspect of science). A generative learning model seriously applied to the study and teaching of teachers promises to greatly increase our understanding of teachers and their worlds, and will help innovators/researchers to learn the language of teachers' practice.

Summary

There has been an evolution of the roles of participants in the endeavor of educational change. Innovators have gradually taken on the roles of researcher and teacher educators, teachers-as-learners are becoming more active in the interaction with innovators/researchers. New ideas about teaching teachers come from a constructivist view of the learning process, and specifically, from work being done on children's learning in science. Pre-service models for teacher education, and curriculum development work with secondary teachers suggest useful ways that in-service elementary teachers might be worked with in the endeavor of educational change. The consideration of the teacher-as-learner using a generative learning model will help shape even more powerful ways for researchers/innovators/teacher educators and teachers-as-learners to cooperate in educational change efforts.

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Health Education for Children
Developing a New Strategy

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Summary

The present status of health education in the first level schools has been investigated in Rio de Janeiro. Emphasis was given to the teachers' and students' concepts of health. The data was used as a basis to develop instructional materials in order to improve the health education for young children. The strategy consists in using a story format combining literature and didatic contents to present different aspects of the health information. Preliminary results show that the instructional material is serving its purpose.

Introduction

Systematic research about health has been recommended by the World Health Organization (1969) in order to improve the educational programs and the relationship of health behavior for a person's beliefs and attitudes. According to Gochman (1971) "If health educators knew more about the 'organization' of various health beliefs at different ages, they might plan programs with optimally effective content and timing." The importance of identifying students' conceptual knowledge and beliefs and the use of this information in planning the materials and strategies for learning was also pointed out by Novak (1977).

Kalmins and Love (1982) emphasized that researches on children's health beliefs from the cognitive developmental perspective, had demonstrated that the quality of children's thoughts about health changes as a function of cognitive development. In this way, the study of Bibace and Walsh (1980) described three major types of explanation consonant with Piagetian stages of cognitive development. The authors found two kinds of prelogical explanation of illness: phenomism and contagion, that reflect children being overly swayed by the immediacy of some aspects of their perceptual experiences. The concrete logical reasoning is manifested in children between 7-10 years of age and reflects an accentuation of the differentiation between what is internal and what is external to the self. The authors also pointed out two explanations of illness characteristic of this age group as: contamination, and internalization. From these results the authors commented that children's books on illness most often are based on adult's construction of how children must think about such phenomena rather than on empirical data revealing how children actually think. They also observed that educational materials are usually written without taking into consideration specific variations in understanding among children at different levels of cognitive development. Researchers who had investigated the formation of health concepts suggested that the understanding of children's health concepts is a prerequisite for health education programs for children. Blos (1978) has affirmed that it is necessary for adults to comprehend how children think so that they can elicit information about children's way of thinking and correct any wrong conclusions.

Several studies have demonstrated that the younger children need some concrete external cues in order to understand what is happening to them when they are ill (Neuhauser et al, 1978). Kalmins and Love (1982) also mentioned that children can judge from other people only by external cues. Bibace and Walsh (1982) suggested that the younger children would focus primarily on external observable events. The latter authors concluded through their studies that the degree of personal control one perceives is directly related to his cognitive developmental status. So, children's sense of personal control increases with the degree of development. Neuhauser indicated that the personality factor of locus of control influenced the children's responses to the more abstract situation. Besides this, Gochman (1972) commented that health motivation plays a role in organizing health relevant beliefs. In his opinion, health behavior must be viewed as an interaction of three determinants of a person's perception: perceived vulnerability, perceived seriousness and perceived benefits. The perception of vulnerability refers to a person's expectancy of being susceptible to some health problems. The seriousness perception denotes the degree to which he believes that encountering this problem will have severe consequences for him. Perceived benefits refers to the expectancy that certain behaviors will lead to desired health outcomes. According to Gochman (1972) high levels of perceived vulnerability, seriousness and benefits presumably interact to increase the likelihood of a person taking or intending to take some health action. Then, he emphasizes that teaching might be geared more towards increasing the children's perception of vulnerability to health problems to some level that might affect their behavior rather than toward teaching particular facts about diseases. But, Kalmins and Love (1982) commented that these suggestions raise some serious ethical questions for health education. It may be justifiable to increase an individual's perception of vulnerability when there is data based in reasons to suspect risk and when there are specific recommendations which will reduce the vulnerability.

In this way, research might be undertaken to determine wether some high risk groups have low expectancies of encountering a variety of health difficulties, and if those perceptions act as a barrier to preventive or adaptive health behavior.

It is important to take into consideration that no evidence was found that the acquired knowledge may be translated into health behavior actions among children. Rothman and Byrne (1982) pointed out that the experience of health educators have been that the knowledge of health or health practices can be increased but the translation of such knowledge into attitude and behavior has been difficult and mostly unsuccessful.

All the studies recommend the necessity of beginning health education in earlier grades in order to obtain some improvement. Gochman demonstrated that a general concept of health may be too abstract for the young child to grasp. According to him, " because specific illness or accidents (for example, cut fingers and colds) are concrete, tangible components of the child's experience, they are more readily integrated into his perceptual system. " He pointed out that longitudinal research has confirmed the stability of a person's expectancies of illnesses and accidents, then attempts to change the level of a perceived vulnerability conceivably might begin far earlier in the person's life. This affirmative can be reinforced if it is considered the relatively lower degree of consistency observed in children under ten years as commented by Gochman (1972) and then, they might be more receptive than older ones to educational programs designed to change these expectancies. The author recommended that health education programs for children in the fourth grade or below oriented to a variety of specific diseases or health difficulties might be more effective than programs geared to a concept of health as something above or beyond the absence of disease.

From these perspectives, the objective of this project has been to survey the present status of health education in both public and private first level schools of Rio de Janeiro. Emphasis was given to teachers' and students' concepts of health and illness for the development of health education materials proper to primary schools.

Method

The plan consisted of interviewing teachers and students from a total of 30 schools in Rio, 15 of which are private, and 15 of which are public. Additionally, the schools were subdivided into three 10 school groups, each one representing one of the city regions: North, South and East. So far, only results from the Northern area have been compiled and analyzed. The sample of teachers included 98 from primary schools and 23 from junior high schools and 398 students from all grades (first to eight grade) of the first level schools (196 from private and 197 from public schools).

The students' age ranged from 7 to 18 and they came from all social classes. They were chosen by a random way in each school, and the public and private schools were matched by the social-economic conditions and locations.

The first and the second grade students were interviewed informally, whereas the other students and teachers completed a questionaire that included questions conscerning basic knowledge about health, opinions and attitudes. (Table I)

The teachers and students were assured of anonimity and confidentiality, and were also allowed to decline participation whenever they wished.

One of the questions about health asked to teachers and students was: " In your opinion, what is health ? " The total of answers from the sample was organized into categories in order to obtain a quantitative analysis about the way teachers and students describe health and the cognitive elements they use in their description of health. Each category was defined in an operational way, so as to guarantee the objectivity of the analysis. To define the categories, it was taken into consideration not only their contents but also the form, so that both the meaning and the richness of the answers were not lost.

Every answer from each person could be included in more than one category, if there was more than one kind of idea presented in it. Thus, the total number of answers could be more numerous than the total number of subjects interviewed.

To explain the categorization process, it is important to exemplify each step of the work. All the answers were listed (some examples - Table II). Then, each answer was analyzed and divided into categories if there was more than one idea presented in it. All the categories were defined operationally (some examples - Table III). Some categories were divided into sub-categories.

Results

Information so far obtained through the questionnaires and interviews with teachers and first-level students were quantitatively and qualitatively analyzed. (Boruchovitch et al, 1987; Rozemberg et al, 1987; Schall et al, 1987) and have indicated that:

(1) The teachers have little knowledge of the programme of health studies stipulated by Educational authorities.

(2) Health studies are poorly related with other disciplines, as well as with the student's age.

(3) The subjects taught bear little relation to the community health problems.

(4) Teachers and other school staff are usually unaware of the student's health conditions, thus tending to neglect problems which need medical assistance.

(5) Teachers and students have a poor knowledge of important health issues, such as the dynamics of transmission of endemic parasitic diseases which are common in Brazil. (Schall et al, 1987).

Teachers' Concepts of Health

The teachers' answers were divided into seven categories (Table IV). The most frequent descriptions were : " well-being " (40.3 %), " good equilibrium or good physical conditions " (23.4 %), and taking care of one's health " (14.5 %). The most common answer was " Health is the mental and physical well-being. " Only six individuals out of 98 (roughly 5%) emphasized the social aspect of health in their concepts of health.

Students' Concepts of Health

The students' answers were divided into eleven categories and thirty-seven sub-categories (Table V). Although there was a great number of qualitative categories, the quantitative analysis (Table VI) demonstrated that the students concentrated their answers in three main categories: " Health as values or qualities " (22.6 %). " Health as feeling or sensation " (13.9 %) and " Health as doing or taking care " (38.9 %). The first category implies the idea of a judgement; the second, the idea of an emotion and the third one, the idea of performing an action.

Two percent (second graders) to 22.2 % (sixth graders) of the answers showed distortion, redundance or inexistence of the contents. From 6.2 % (first graders) to 11.1 % (seventh graders) of the answers showed an understanding of health as being an absence of illness or problem.

The category " Health as doing or taking care. " was higher in the lower grades, decreasing as the grades increased. The percentage of the category " health as feeling " has an opposite tendency, increasing according to the grade levels. The category " Health as values or qualities " in general had almost similar percentages in all grades.

The Development of the Material

From the results of the interviews and because of the obvious lack of appropriate health education materials for young children from primary school, the project's second stage had been to produce and to evaluate instruction materials taking into consideration the cognitive aspects that is proper in this age group.

To make this information more interesting to the student, we decided on a story format as a device to obtain the following objectives:

(1) Have students identifying themselves with the characters.

(2) Make them relate it to their own experience.

(3) Encourage them toward action.

The role of the story is to encourage the active interest of the parents, teachers and students through linking learning and the environment in 3 different ways:

(1) Through the acquisition of basic knowledge.

(2) By observing the physical conditions of the environment which cause illness.

(3) By being encouraged toward community health prevention.

Using a story format, not only are health messages presented, but also favor students to perform free play situations. The teacher can explore their students' ideas about the characters they meet in the story within an atmosphere of participation, freedom and creativity. Thus, the material can have both informal and formal functions and also be integrated throughout several subjects in the curriculum.

The first materials developed consist of a collection of 6 story books, called " Ciranda da Saude ". The subjects of the books were selected from the most important problems of health that affect the Brazilian children, such as: dental caries, lice infestation, Chagas' disease, nutrition, yellow fever, worms in general and schistosomiasis in particular.

The instruction materials include:

(1) The illustrated booklet (Table VII) in which the information is conveyed on a literary form adequate for children from 7 to 12 years of age.

(2) Leaflets containing more detailed information about the subjects treated in each case.

(3) A guide-book aimed at providing the teachers with relevant information on the principles of health education.

Although the subjects of the booklets are specific to Brazilian children's health problems, the instruction material (leaflets and guide-book) directs the teachers to a work which would bring about discussion concerning health aspects which are universal, such as its role in preventive medicine. The books include directions about how to develop extra-curricular activities such as games, story-telling, dramatization and excursions. Suggestions on how to promote the participation of the family and the community are also given.

It is important to mention that two books (about lice infestations and dental caries) were already published in Brazil. These books were considered appropriate to the philosophy of the collection and the authors agreed to participate in the project.

The other books and leaflets were developed for the project and the writers were oriented by scientists and members of the group in order to provide them the scientific knowledge to prepare the materials (texts) and to engage them in the philosophy of the collection. The guide-book was written by several specialists in health education. This collection has been tested in 150 schools in Rio de Janeiro since March 1987 and the work is expected to be completed by July 1988. The experimental design of the test for these materials is based on the Solomon procedure. As a control material, some chapters of a traditional science book were used.

The first results has been evaluated statistically (Schall et al, 1987) indicating that children that were in contact with one of the books " Ciranda da Saude " collection have improved their knowledge of health matters. Besides this, students who have learned through " Ciranda da Saude " gave more social messages in

their answers than the students from the control group.

Discussion

The analysis of the children's concepts of health confirms the data referred in the literature of this area. As Kalmins and Love (1982) in response to the question "What is health ?". children whose cognition reflects the features of concrete thought give listings of specific acts, events or rules for maintaining health. On the other hand, the increase of the conception of health as a feeling through the grades may demonstrate also a development of the students' ability to integrate their feelings and experience in health into a conscious, communicable concept of health as a positive state of being. In addition, it is important to mention that both teachers and students' concepts of health did not take into consideration the social aspects in their answers. In a country where several diseases are related with environmental and social conditions, this kind of teacher and children answers can demonstrate a lack of awareness of the reality around them.

From these results, the collection of books was developed in a way to offer children opportunity to make a relation between health issues and their own life. The instruction materials for the teachers tend to improve their attention to the social aspects of health. This proposal seems to be appropriate since the first results gave evidence that children who were in contact with the books of " Ciranda da Saude " reported more social aspects in the post-test than in the pre-test and also in comparison with the children of the control group (Schall et al, 1987).

Besides this, informal evidence through reports from teachers could demonstrate the occurence of behavioral change as: (1) in a school where the material was used, students tended to buy less candy than they used to, (2) in another school, the third grade students started a campaign to eliminate lice infestation. Teachers reported that most of the students used to feel shy in admitting they had lice in their own hair. After using the material, they were able to discuss about lice freely. (3) Teachers also commented that several students mentioned interest in developing campaigns to preserve the environment as, for instance, cleaning polluted rivers.

Although these first results indicate that the material is serving its purpose, for this strategy to be successful, teachers have to be trained. A teacher training course on health education is necessary, not only to orient the use of the collection, but also to give basic information as follow:

(1) Education in general and health education in particular.

(2) Health as a human right.

(3) The care of the body, the home, the school and the world.

(4) Discovering your own body. How to teach about sex in the first grades.

(5) Health and school failure.

(6) The relationship between teachers and

students from Rogers' perspective of learning.

(7) Health and environment.

(8) The main diseases and health problem of Brazilian children.

(9) The main transmissors of diseases and the different ways of transmission.

(10) Learning about ethiology of children's diseases.

(11) The problems of the handicapped child and how to cope with them.

(12) Danger at home, in the school and in the street - First-aid, vaccination and the use of the serum.

After each unit, teachers will practice how to teach about health by using different kinds of creative activities such as: games, story telling, dramatization, puppet shows, excursion and art craft techniques, all related with the collection " Ciranda da Saude ".

Since the main goal of health education is to promote behavior changes or to develop preventive attitudes, the learning in this area has to be more affective. According to Rogers (1969), we are becoming more conscious of the importance of the affective development and the need to orient its growth in the schools. The emotional aspects of the students cannot be ignored, and the schools may be able to perform an important task in this sense. It is obvious that there is an affective learning in the schools, but a great part of this learning is casual to the school's objectives since it does not belong to the curriculum. Unfortunately, even with all the resources existent in the learning field, much of the learning process at the schools is still based on listening, reading, memorizing, repeating and forgetting.

Through the use of the collection " Ciranda da Saude " the learning process can be more practical, pleasant and collective. The possibility of the students identifying themselves with the characters may be considered a form to promote associations with human contents. These associations are positive and provide emotional supports for other challenges.

Although this collection is destined to Brazilian health problems, the strategy of using a story format to present information for children, may be extended to specific problems of other countries. Besides, stories dealing with mental, psychological, health issues and also social values can be created in order to improve the affective learning which is missing in the schools nowadays.

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Table I - Questionnaire for Teachers and Older Students

Subject	Number of Questions	
	Teacher	Student
A - Personal data		
B - Concepts of health and illness	3	4
C - Nutrition and health	7	4
D - First-aid	2	2
E - Personal hygiene	3	3
F - Knowledge about Brazilian children's diseases	17	11
G - Drugs, alcohol and cigarettes	3	1
H - Polution and conservation of the environment	2	3
I - Mental health	6	0
J - Herbal medicine and folk-cures	2	2
K - Attitudes and opinions	12	12
Total	57	42

Table II - Some Examples of Students' Answers to the Question " What is health ? "

Health is ....

1 - To feel well, to have disposition, to be motivated to do everything, to run, to jump... to be healthy.

2 - To help the people, to teach.

3 - Is something we have. It is a healthy person who eats well.

4 - It is very good to be healthy. The one who is healthy lives with peace. If people do not have vices, the world would not be so cruel. If something bad happens to people, they become addicted, they forget about health and they do not mind about anything else.

5 - To have a good diet, complete hygiene, to eat the right food, not to eat a lot, but the necessary.

6 - A person who has love and care.

7 - Is joy, cheerfulness.

8 - Not swimming in dirty rivers, not playing in the ground, not stirring in the street's dimples.

9 - To have Father and mother, to feel closer. One has more health.

10 - To have rights, to study.

11 - To have school and food.

12 - To take care of ourselves.

Table III - Same Examples of Operational Definition.

Health as "Doing" or "Taking Care": All the answers, including ideas of bio-psycho and social preservation. This category is divided into: In General; Physical Care with : Feeding, Hygiene, Treatment; Physical Prevention; Physical Activity; Appearance; Sleep/Rest/Breathing; Mental Care; Mental and Physical Leisure; Social Care - Helping Others; Consciously Acting Againsts One's Own Health; Mental-Physical-Social; Activity of Life.

Some examples of how the categories are operationally defined :

In General - Answers that give the idea of care without any mention of specific actions.

Ex: " Health is a thing we must have much care of."

" Health is a person who knows how to take care of himself. "

Physical Care With:

Feeding - Answers in which health is related to eating.

Ex : " To be healthy is to eat well."

Hygiene - Answers in which health is related to a practice of hygienic measures with one's body, the food and the house.

Ex : " Health is a person who is clean, that does not eat dirty things, and before eating washes the things."

" Health means to have a good nutrition, to have alway hygiene, to wash the fruits, to take a bath, to clean the nails, and to keep clean the environment we live. "

Treatment - Answers which associate health with behaviours of searches for medical, odontological, pharmacological and other prophylactic measures.

Ex : " Health is to go to the doctor, to the dentist and not to walk barefoot."

Physical Prevention - Answers which indicate the idea of avoidance of doing things considered to be harmful in a physical dimension.

Ex : " Health is a person that doesn't drink dirty water, doesn't take baths in polluted rivers, and doesn't walk on puddles."

" Health is not taking bath in a river in order not to become sick, not eating fish from polluted waters and not walking on puddles."

Physical Activity - Answers which relate health to the performance of physical actions.

Ex : " Health is running and jumping.

" Health is having a strong body, is practicing sports."

Social Prevention - Answers which indicate the idea of avoidance of doing things considered to be harmful to health in a social dimension.

Ex : " Health is to eat well, is not to run after lunch, is to play, is to be a good boy, is to have regard toward the teacher, is to play well with friends and it is not to fight in lunch time to be first. Health as an Absence of illness or Problems : All the answers in which health appears as not having or being with diseases or problems.

Ex : " Health is not having any disease."

Health as the Guarantee of Basic Conditions for Survival: All answers referring to the need of family care, education and social conditions.

Ex : " Health is to have an education."

" Health is to be brought up at home, I was brought up at the street."

" Health is to eat well, to have what to eat."

Table IV - Teachers' Concepts of Health and Illness (N = 98)

Categories (Health)	Number of Answers (%)
1 - Good physical conditions Healthy bodily functions / good equilibrium.	29 (23.4)
2 - Well-being	50 (40.3)
3 - Taking care of one's health	18 (14.5)
4 - Disposition and energy	7 (5.6)
5 - Absence of illness	8 (6.5)
6 - Health values	4 (3.2)
7 - Undecided and no response	8 (6.5)
Total of Answers	124 (100)

Table V - Categories and Sub-Categories of Students' Health Concepts

1.0 Don't know
2.0 Gave redundant answers
3.0 Gave distorted answers
4.0 Health values or qualities
    4.1 Related to health in general
    4.2 Related to life
    4.3 Personal
        4.3.1 General
        4.3.2 Physical
        4.3.3 Mental and emotional
        4.3.4 Behavioral
    4.4 Social
5.0 Health as a feeling
    5.1 General
    5.2 Feeling of life
    5.3 Physical sensation
        5.31 Having well functioning organs
    5.4 Mental and emotional
    5.5 Mental and physical
    5.6 Mental and social
6.0 Health as "doing" or "taking care"
    6.1 In general
    6.2 Physical care
        6.2.1 With feeding
        6.2.2 Hygiene
            6.2.2.1 Personal
            6.2.2.2 With food
            6.2.2.3 With housing conditions
        6.2.3 Treatment
        6.2.4 Physical prevention
        6.2.5 Physical activity
        6.2.6 Appearance
        6.2.7 Sleep, rest and breathing

6.3 Mental care

6.4 Mental and physical leisure

6.5 Social care : helping others

6.5.1 In general

6.5.2 Social prevention

6.5.3 Care given by others

6.5.4 Lack of care from others

6.6 Consciouly acting against one's health

6.7 Mental, physical and social

6.8 Activity of life

7.0 Health as the guarantee of the basic conditions for survival

8.0 Health as a possibility

9.0 Health as absence of illness or problem

10.0 Health as the description of symptons of lacking health

11.0 Health as not needing other people to take care of you

Table VI Students' Concepts of Health - Questionnaire Showing the Percentage Categories

What is to be healthy ?
How would you describe a healthy child ?

Categories	1st	2nd	3rd	4th	5th	6th	7th	8th
Number of Answers	97	99	76	57	73	63	72	88
Don't know	8	2	8	14	8	13	6	0
Redundant answer	1	0	5	5	11	6	8	1
Distorted answer	2	0	3	3	0	3	0	0
Health values or Qualities	29	21	28	23	23	22	21	16
Health as a feeling	7	10	11	11	11	21	19	24
Health as "doing" or "taking care"	43	51	30	37	27	22	28	47
Health as the guarantee of basics for survival	3	0	0	0	3	0	3	2
Health as a possibility	0	0	7	0	1	2	1	0
Health as an absence of illness or problem	6	11	7	9	10	10	11	9
Health as no health	0	0	1	0	3	0	3	0
Health as not needing other people to take care of you	0	3	0	0	1	2	0	1

Table VII - Books of the Collection " Ciranda da Saude "

(1) Marucia Berriel Neto - Memorias do Pimpolho - Rio de Janeiro - Ed. Antares (1985) (about lice infestation)

(2) Ana Maria Machado - Balas, Bombons e Caramelos - Rio de Janeiro - Ed. Antares, 1985 (about dental caries)

(3) Carlos Pimentel - Quita, a Mosquita - Rio de Janeiro - Ed. Antares, 1986 (about yellow fever)

(4) Virginia Schall - O Feitico da Lagoa - Rio de Janeiro - Ed. Antares, 1986 (about schistossomiasis)

(5) Ana Clara Ribeiro - Guerra nas Entranhas - Rio de Janeiro - Ed. Antares, 1986 (about worm infestation)

(6) Virginia / Maura - Na Pista do Perigo - Rio de Janeiro - Ed. Antares, 1987 (about Chagas' disease)

THE PROCESS OF CONCEPTUAL CHANGE IN SCIENCE: A CASE STUDY OF THE DEVELOPMENT OF A SECONDARY PUPIL'S IDEAS RELATING TO MATTER

Philip Scott, University of Leeds, England

1. Introduction

This case study follows the progress of an individual student through a teaching sequence relating to the particulate theory of matter. The teaching was carried out in a normal class situation with the teacher acting as researcher within his own laboratory. Data were collected to monitor the development of the pupil's ideas and an attempt was made to isolate those factors which are of influence in either encouraging or discouraging conceptual change.

2. Context of the Study

2.1 The School and Class

The study was carried out in a co-educational high school situated on the edge of a large industrial town in the North of England. Approximately 900 students between the ages of 11 and 18 years attend the school.

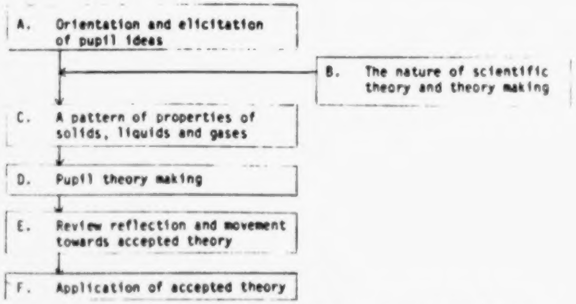
The teaching involved a class of fourteen year olds (14 girls and 11 boys). The class (3A2) was a 'middle set' within the year group, and the students might therefore be considered to be of just above average ability, according to national standards. Staffroom opinions of 3A2 found some consensus with comments such as, 'harmless but not very bright' and 'they need continuous pushing'.

2.2 The Student

Sharron, a member of class 3A2, was the subject of this case study. At the time of teaching (December/January 1985/86) Sharron, both in appearance and behaviour, was considered by the teaching staff to be rather non-conformist. Her unusual hairstyle and imaginative interpretation of school uniform regulations had resulted in one or two minor clashes with school authority. Academically she was considered to be of slightly above average ability in all the subjects which she studied.

2.3 The Course of Study

The 'particles teaching scheme' was prepared by a working group of the Children's Learning in Science Project and the author of this study was a member of that group. The scheme (CLIS 1987) is based upon a constructivist view of learning (Driver and Bell 1985; Driver and Oldham 1986). It can be broken down into a number of sections as shown in Fig. 1. A brief description of each section now follows.


A. Orientation and elicitation of pupil ideas
B. The nature of scientific theory and theory making
C. A pattern of properties of solids, liquids and gases
D. Pupil theory making
E. Review reflection and movement towards accepted theory
F. Application of accepted theory

Section A: Elicitation of pupil ideas - the means by which the teacher becomes aware of pupil ideas and pupils become aware of their own ideas relating to various properties of matter.

Section B: The nature of scientific theory - the pupils will be actively involved in scientific theory-making at a later stage in the scheme. They therefore should be introduced to the nature of scientific theory and theory making.

Section C: A pattern of properties - theory making may be based upon spotting patterns of behaviour. In this section pupils consider patterns of properties in the behaviour of solids, liquids and gases.

Section D: Theory making - the pupils develop their own theories as to the nature of solids, liquids and gases.

Section E: Towards accepted theory - pupil theories are composed and evaluated by the members of the class. The teacher introduces activities which encourage pupils to further evaluate, develop and change their ideas.

Section F: Application - pupils are given opportunities to try out new ideas about the nature and behaviour of matter, in both familiar and novel situations.

Fig. 1 The particles teaching scheme in outline

3. Theories of Conceptual Change: A brief review of the literature

The following survey focuses upon those parts of the conceptual change literature which are relevant to the present study.

Posner, Strike, Hewson and Gertzog (1982) have developed a model of conceptual change which is largely derived from current philosophy of science. The process of assimilation (where the student uses existing concepts to deal with new phenomena) is related to Kuhnian normal science and accommodation (where central commitments require modification) is related to what Kuhn terms revolutionary science. Both modes of learning are considered to occur against the background of the learner's current concepts (conceptual ecology). Features of an individual's conceptual ecology which are considered to be important determinants of the direction of an accommodation include anomalies, epistemological commitments and metaphysical beliefs. Hewson has pointed out the importance of epistemological commitments (Hewson 1984) and metaphysical beliefs (Hewson 1980) in learning science. Posner (1983) suggests that this view of conceptual ecologies should be broadened.

Nussbaum and Novick (1982) have developed methods for promoting cognitive accommodation in the classroom by the use of 'conceptal conflict'. They refer to the potential importance of an individual's metaphysical beliefs in guiding conceptual change and describe major conceptual change as being an evolutionary process.

Wittrock's theory of generative learning (Wittrock 1974) is based upon both the constructivist and information-processing traditions. The fundamental premise of generative learning is that people must construct perceptions and meanings for themselves. The perceptions and meanings are additional both to the external stimuli and to the learner's existing knowledge. Osborne and Wittrock (1983, 1985) have developed a model of learning based on the generative theory.

Solomon (1983) focuses on the social construction of children's scientific knowledge and suggests that students should be able to think and operate in two different domains of knowledge and be capable of distinguishing between them. The two co-existing spheres are referred to as 'life-world knowledge' and 'scientific knowledge'. Solomon draws upon the work of Schutz and Luckmann (1973) to develop her analysis. She suggests that the deepest levels of understanding are achieved by the fluency and discrimination with which we learn to move between these two contrasting domains of knowledge. Barnes (1976) has developed ideas parallel to those of Solomon in making a distinction between 'action knowledge' and 'school knowledge'. He claims that once school knowledge has become incorporated into that view of the world on which actions are based then it has become action knowledge. Action knowledge refers to pupils' assimilation of knowledge to their own purposes.

Both Barnes and Solomon have stressed the importance of language in learning. Barnes (1976) argues that, through language, old experiences can be represented to ourselves anew. Talk and writing provide means by which children are able to reflect on the bases upon which they are interpreting reality, and thereby change them.

4. Collection of Data

4.1 Written data: Students completed the same written diagnostic test before and after the teaching of the lessons. Some of this test data is included in Section 5. Throughout the lessons, all students kept a diary in which they recorded reflections about the lessons plus notes on any issues of concern or interest. In addition, the students, working individually or in small groups were asked at various points to record in writing their ideas relating to a range of phenomena. All of these written data were collected for analysis.

4.2 Audio-tape data: Throughout the sequence of lessons, students participated in a number of small group discussion sessions. On each occasion the discussion group of which Sharron was a member was audio-taped. The teacher also taped individual interviews with Sharron and with the other three members of her discussion group.

Fig. 2 shows the sequence of taped material and lessons.

Tape	Date	
	1985	
	November 12	Lesson 1 (A)
	November 14	Pre-test
T1	November 19	Lesson 2 (A)
T2	November 20	
T3A	November 21	Lesson 3 (B)
T3B	December 3	Lesson 4 (C)
T4A	December 4	
	December 5	Lesson 5 (C)
T4B	December 6	
T5A	December 10	Lesson 6 (D)
T5B	December 11	
	December 12	Lesson 7 (E)
T6A	December 13	
	December 17	Lesson 8 (E)
	December 19	Lesson 9 (E)
T6B	December 20	
	1986	
	January 7	Lesson 10 (E)
	January 9	Lesson 11 (E)
T7A	January 10	
	January 12	Lesson 12 (F)
	January 21	Lesson 13 (F)
	January 23	Post-test
T7B	January 29	

Letters A - F indicate sections of the course (see Fig. 1)

5. The Case Study

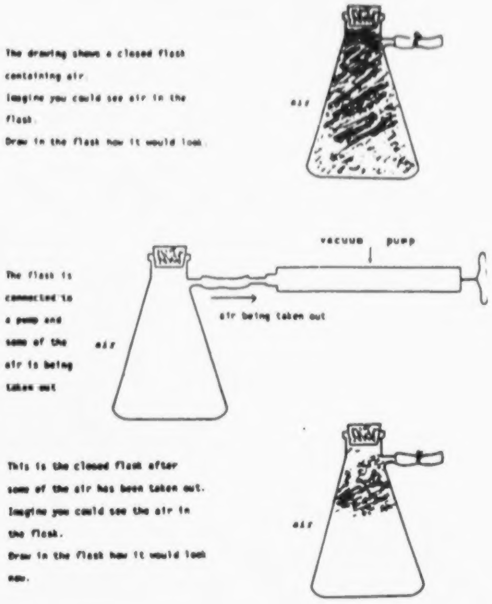
This section is divided into three parts. Firstly Sharron's beliefs and ideas about the nature of matter at the commencement of teaching are considered. Attention is then focussed upon her ideas at the end of teaching. Finally an analysis is made of the key features in the development of her ideas from start to finish of the lesson sequence.

5.1 At commencement of teaching: The student's beliefs and ideas.

5.1.1 The pre-test

Three questions from the pre-test have been selected and the student' response for each examined.

a) Flasks



The drawing shows a closed flask containing air.
Imagine you could see air in the flask.
Draw in the flask how it would look.

The flask is connected to a pump and some of the air is being taken out

This is the closed flask after some of the air has been taken out.
Imagine you could see the air in the flask.
Draw in the flask how it would look now.

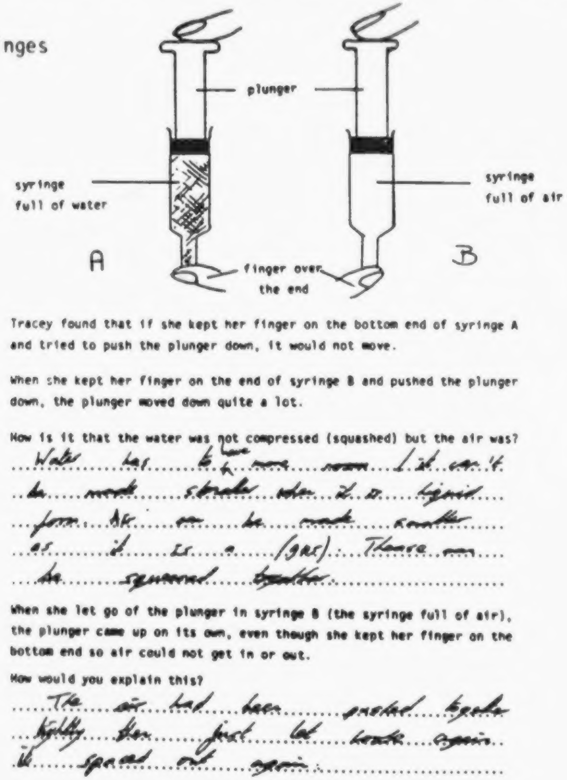
Fig. 3 Flasks: Pre-test

Sharron shows the air in the first flask by means of a continuous shading. After some air has been removed, she again uses continuous shading - but limited to the top part of the flask.

Sharron later (T2) explains her ideas by stating that, 'everything will have been pumped sort of upwards'.

On being questioned about what is left at the bottom of the flask (unshaded) Sharron replies (T2),
'Well I think there'll be a bit there still, but not so much or none at all but that'll probably all drift down again...'

b) Syringes


plunger
syringe full of water
syringe full of air
A
B
finger over the end

Tracey found that if she kept her finger on the bottom end of syringe A and tried to push the plunger down, it would not move.

When she kept her finger on the end of syringe B and pushed the plunger down, the plunger moved down quite a lot.

How is it that the water was not compressed (squashed) but the air was?

Water has to have more room. It can't be made smaller when it is liquid form. Air can be made smaller as it is a (gas). These can be squeezed together.

When she let go of the plunger in syringe B (the syringe full of air), the plunger came up on its own, even though she kept her finger on the bottom end so air could not get in or out.

How would you explain this?

The air had been pushed together tightly then just let loose again it spaced out again.

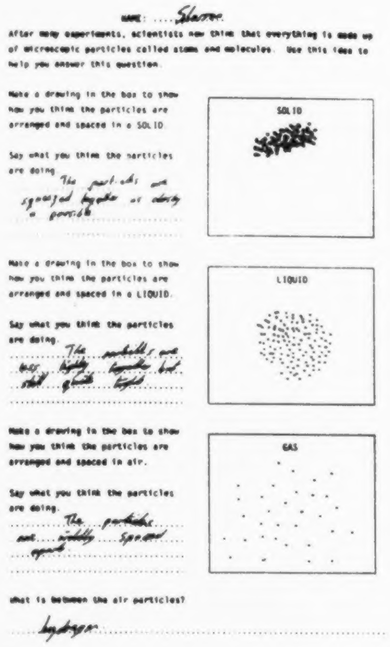
Fig. 4 Syringes: Pre-Test

'Water has to have more room. It can't be made smaller when it is liquid form. Air can be made smaller as it is a (gas). These can be squeezed together.'

'The air had been pushed together tightly then just let loose again it spaced out again.'

Sharron writes that when the depressed plunger is released it returns to its original position as the air 'spaced out again'. This explanation appears to be based upon the notion that the sample of air has its own 'natural volume' which is automatically returned to after squashing.

c) Solid, liquid, gas


SOLID
LIQUID
GAS

NAME: Sharron

After many experiments, scientists now think that everything is made up of microscopic particles called atoms and molecules. Use this idea to help you answer this question.

Make a drawing in the box to show how you think the particles are arranged and spaced in a SOLID.

Say what you think the particles are doing.

The particles are squashed together as closely as possible

Make a drawing in the box to show how you think the particles are arranged and spaced in a LIQUID.

Say what you think the particles are doing.

The particles are less tightly together but still quite tight

Make a drawing in the box to show how you think the particles are arranged and spaced in air.

Say what you think the particles are doing.

The particles are widely spread apart

What is between the air particles?

hydrogen

Fig. 5 Solid, Liquid, Gas: Pre-Test

'The particles are squeezed together as closely as possible'.

'The particles are less tightly together but still quite tight'.

The particles are wildly (widely) spaced out'.

'hydrogen'.

This question provides information about particles. Having been given this information, Sharron produces three diagrams which display groups of 'dots' with increasing spacing between them from solid to liquid to gas.

In interview (T2), Sharron states that she has heard of atoms and molecules before, not in science lessons, but, 'I've heard it round the science block and I've got a book at home about science.'

On being asked what the dots are, she replies, 'Well, em, its sections of the actual thing.'

She then volunteers, 'That's where I got the idea from - from that plunger 'cos that shows that solids are close together and can't be pushed any further and gas is more spread out and you can push them more together like that shows.'

Sharron has used evidence from the previous question (syringes) to help set up a 'particle model'. She agrees that the prompt for using a particle representation came from the question itself, where it is stated that scientists think that everything is made of particles.

5.2 Summary

The data show that prior to the introduction of particles ideas in a pre-test question (solid, liquid, gas), Sharron was happy to frame explanations in macroscopic terms. The interview data indicate that she is willing to invest some thought in considering phenomena and answering questions. In reviewing the various ideas which are introduced and prompted by the pre-test, Sharron observes that she had been

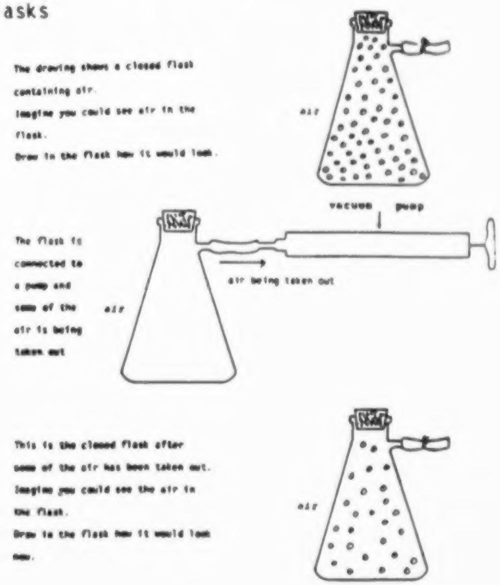
'Sort of fitting them all together'.

5.2 At Completion of Teaching: The Student's Beliefs and Ideas

5.2.1 The Post-test

Consider now Sharron's performance, in the same three questions, at the end of the teaching.

a) Flasks


The drawing shows a closed flask containing air.
Imagine you could see air in the flask.
Draw in the flask how it would look.

The flask is connected to a pump and some of the air is being taken out

This is the closed flask after some of the air has been taken out.
Imagine you could see the air in the flask.
Draw in the flask how it would look now.

Sharron portrays the air in each flask by means of differently spaced particles. In a later interview (T7B), Sharron displays some confidence in dealing with the particle ideas.

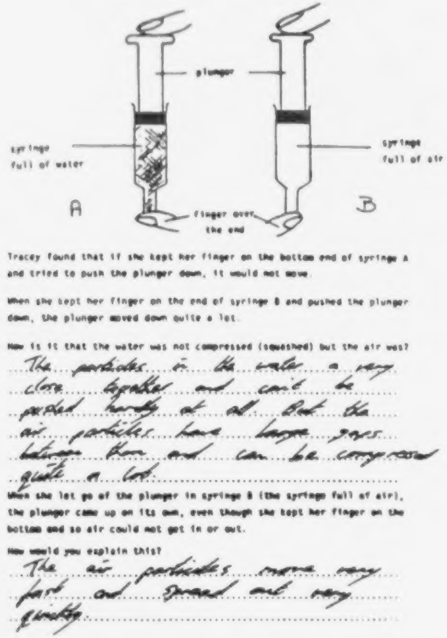
Teacher: So you've drawn them spaced apart [in the second flask].

Sharron: Yeah, but they're still filling the whole flask you see - that's what's wrong there you see [in her pre-test answer].

Teacher: Oh, I see. Why do they have to fill the whole flask?

Sharron: Because they're moving - moving around the whole of the time and you wouldn't just get them half way up.

b) Syringes


plunger
syringe full of water
syringe full of air
A
B
finger over the end

Tracey found that if she kept her finger on the bottom end of syringe A and tried to push the plunger down, it would not move.

When she kept her finger on the end of syringe B and pushed the plunger down, the plunger moved down quite a lot.

How is it that the water was not compressed (squashed) but the air was?

The particles in the water a very close together and can't be pushed hardly at all. But the air particles have large gaps between them and can be compressed quite a lot.

When she let go of the plunger in syringe B (the syringe full of air), the plunger came up on its own, even though she kept her finger on the bottom end and so air could not get in or out.

How would you explain this?

The air particles move very fast and spread out very quickly.

'The particles in the water are very close together and can't be pushed hardly at all. But the air particles have large gaps between them and can be compressed quite a lot.'

'The air particles move very fast and spread out very quickly.'

In judging the second response it should be borne in mind that the notion of air pressure was not raised during the lessons. On being further questioned (T7B) about why the depressed plunger comes up on its own, Sharron invokes an 'all things must return to their proper position' type of argument:

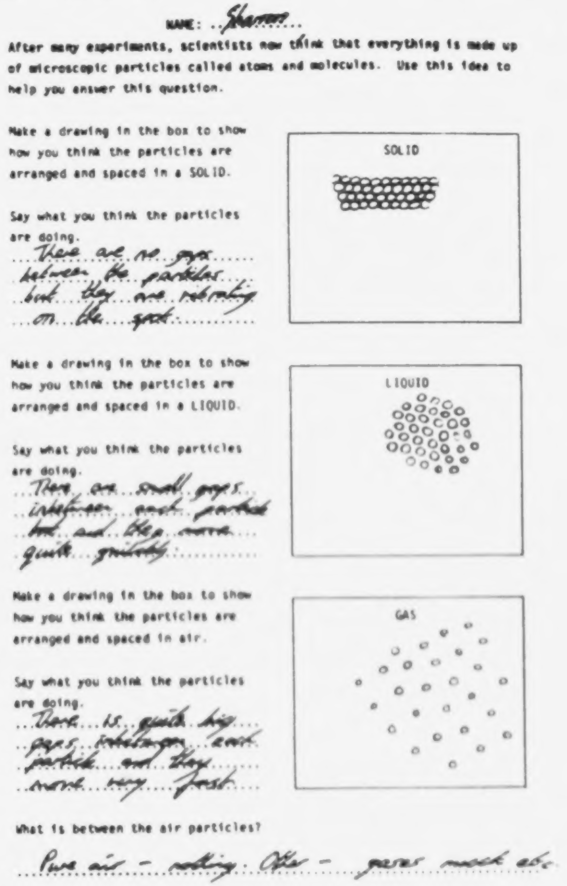
Sharron: You see when you push them down, you sort of putting them in not their proper position and ... that they want to be in.

Teacher: Mmm.

Sharron: So, like, if I was put in a small box then....er I'd sort of push out cos like I didn't have enough space. And I think that's what the air particles are doing.

This line of argument also appears to confer animistic qualities upon the particles. The particles can 'push out' in a small space - like a human being.

c) Solid, liquid, gas



NAME: Sharron

After many experiments, scientists now think that everything is made up of microscopic particles called atoms and molecules. Use this idea to help you answer this question.

Make a drawing in the box to show how you think the particles are arranged and spaced in a SOLID.

Say what you think the particles are doing.
There are no gaps between the particles but they are vibrating on the spot

Make a drawing in the box to show how you think the particles are arranged and spaced in a LIQUID.

Say what you think the particles are doing.
There are small gaps inbetween each particle ~~but~~ and they move quite quickly

Make a drawing in the box to show how you think the particles are arranged and spaced in air.

Say what you think the particles are doing.
There is quite big gaps inbetween each particle and they move very fast

What is between the air particles?
Pure air - nothing. Other - gases muck etc

'There are no gaps between the particles but they are vibrating on the spot'

'There are small gaps in between each particle and they move quite quickly'

'There is quite big gaps in between each particle and they move very fast'.

'Pure air - nothing. Other - gases, muck, etc.'

In interview (T7B) answers to the pre and post test, for this question, were compared. The point is made that movement of particles is not mentioned in the pre-test:

Sharron: Well I didn't think they were moving at that point. But now I think that I should have put that the gas should have been moving ... cos with steam sort of rises. With no force. Just of its own accord.
Teacher: Steam? From where? Can you give me an example?
Sharron: Well, when a kettle is boiling or when you've run your bath.

This exchange presents an example of a situation where the student has employed a non-valid piece of evidence to support her developing ideas. Sharron has extended the developing concept into an inappropriate context (inappropriate in terms of accepted science). In response to another post-test question, Sharron makes a link between particles and bacteria.

Sharron: I didn't really understand bacteria when we did it in second year.
Teacher: Ah-hah.
Sharron: And, em, now I understand it. Cos I didn't understand why, em, the particles [bacteria] grew when it was warm and they didn't when it got cold but now you can see that, em, the particles are further apart when they're warm so that they can move easier and spread quicker cos they can't when they're cold.
Teacher: So are bacteria like particles?
Sharron: Em...yeah.

5.2.2 Comment

The post-test data indicate that generally Sharron has developed some ability and confidence in interpreting and applying the particle theory. This is not to say that her knowledge and understanding are complete.

Sharron displays an impressive willingness to make links between new and existing ideas and obviously gains some intellectual satisfaction from this. In later interview (T7B) she comments that the idea of particles has 'answered a lot of, sort of, questions in my head you know. Em, finding out like, for instance, them experiments we did.'

Sharron shows diligence in attempting to relate the simplified nature of the particle model to the complexities of the real world. Thus in response to the post-test question (c), 'What is between the air particles?' - Sharron writes 'Pure air - nothing. Other - gases, muck, etc.' 'Pure air - nothing' refers to the idealised model which has been the subject of study and discussion. This model includes only one kind of air particle between which there is nothing. With real gases such as air, Sharron points out that there will be more than one kind of gas present plus 'muck etc.'.

In interview (T7B) Sharron was questioned about the relative status of her original (macroscopic continuous) and developing particle, ideas:

Teacher: Which of those two explanations [macroscopic or particle] do you think you'd be inclined to use: You know, in everyday life.
Sharron: Em, that one [macroscopic].
Teacher: The first one you did?
Sharron: Mmm. To someone who's er, sort of, don't know... like if I were talking [laughs] to me mum or summat should I say sort of particles she wouldn't really know what...
Teacher: So are you saying that you, you wouldn't give up that kind of explanation?
Sharron: Well not to someone who .. em, didn't know what the, it means. Like say me mum or someone.

5.3 An Analysis of the Development of the Student's Ideas

5.3.1. Introduction

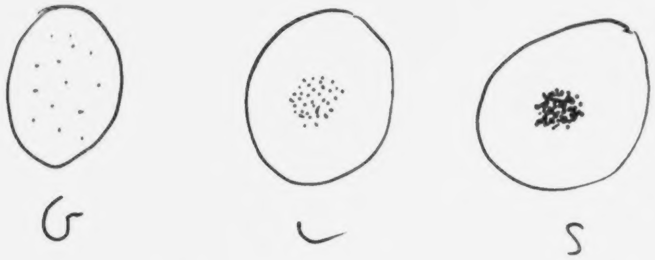
Prior to the teaching, Sharron had a vague awarenesss of the particulate nature of matter - she had come across 'atoms' in a science book and around the school science department. By the end of the course, Sharron was able to refer to and apply a particle model which showed the particles - differently spaced in three phases; in continuous motion; with nothing between them in pure substances; moving more quickly at higher temperatures. Consider now how Sharron's ideas developed from start to finish of the lessons.

5.3.2. The development of the student's ideas

The following extract is taken from an interview with Sharron (T4A) after a lesson on identification and classification of solids, liquids and gases (Fig. 1 Section C). The teacher is trying to establish how Sharron views the internal structure of the three phases. It is important to note that particle ideas have not been addressed in any of the lessons thus far (although particle ideas were introduced in a pre-test question).

Sharron: Em - well whatever its made of is sort of pushed so far as it can together in a solid.
Teacher: Had you thought what it might be like inside a gas?

Sharron: Er, I think its summat to do with the air, er .... and the, em, the distance in between each of the substance like metal and, em, liquid.
Teacher: Could you make a drawing of what you're thinking, or not?
Sharron: Yeah.
Teacher: You sketch down what you think a solid would be like.
(Pupil draws out solid, muttering)



Sharron completes the drawings for solid, liquid and gas. She explains the differences in particle separation by referring to the syringe experiment. 'The gas will not be very close together cos that can be pushed down.' Sharron then refers to the particles as 'molecules'.

Teacher: What's this word 'molecules' you've just said?
Sharron: Well, the parts of the metal.
Teacher: How big are they - do you know?
Sharron: Em, well I think they'll be really tiny.
Teacher: Where did that word come from Sharron? You've never said that before now.
Sharron: Em, in the test sheet at the start [pre-test]

The teacher then asks Sharron where she had got the idea for the diagrams from.

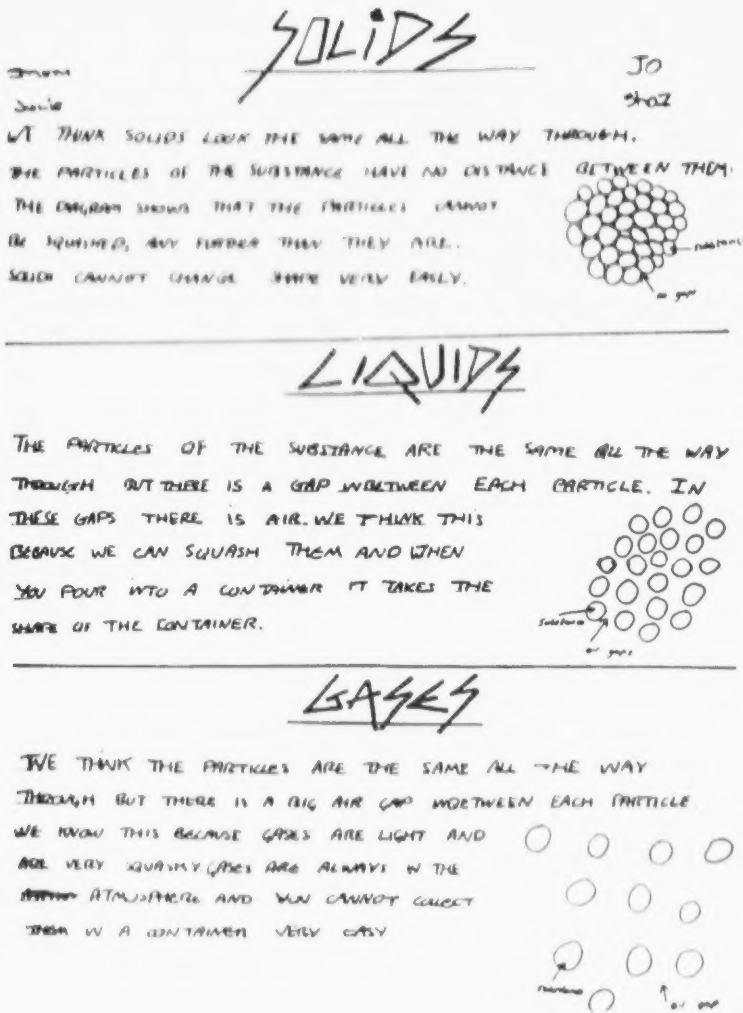
Sharron: Through fitting together everything - you know like the experiments we did.
But that would be a microscopic view of it.
Teacher: What do you mean by microscopic Sharron?
Sharron: Em, well you wouldn't be able to see that with your own eyes sort of thing. That would be magnified a few times.

At this stage, Sharron's theory of the internal structure of matter is based upon ideas prompted by the pre-test questions and the syringe activity. The three phases are represented by static particles at various separations. Sharron shows some awareness of her own learning when she states that she had been 'fitting together everything'. Her reference to the microscopic scale of the particles, 'that would be magnified a few times', leaves doubts as to her appreciation of the size of molecules.

The following piece of transcript was recorded after lesson 5 (T4B). Sharron is describing what exists between the particles in her diagrams of solids, liquids, gases.

Sharron: In between that [solid particles] there's probably.. Well I don't think there'll be any gaps at all in a solid. So it'll just...
Teacher: Be right close.
Sharron: Yeah. But with that [pointing at her diagram] with the liquid, there'll be sort of like oxygen or air or summat.
Teacher: Between the dots?
Sharron: Yeah.

At this stage there has been no discussion of the structure of matter within the lessons (the lessons have been directed towards the classification and properties of matter). During lesson 6, (Fig. 1 Section D) Sharron and her three friends were involved in developing their own model for solids, liquids, and gases. They summarised their ideas in a poster in Fig. 3.


SOLIDS

[illegible]
Josie

JO
Shaz

WE THINK SOLIDS LOOK THE SAME ALL THE WAY THROUGH. THE PARTICLES OF THE SUBSTANCE HAVE NO DISTANCE BETWEEN THEM. THE DIAGRAM SHOWS THAT THE PARTICLES CANNOT BE SQUASHED ANY FURTHER THAN THEY ARE. SOLIDS CANNOT CHANGE SHAPE VERY EASILY.

particle
no gap

LIQUIDS

THE PARTICLES OF THE SUBSTANCE ARE THE SAME ALL THE WAY THROUGH BUT THERE IS A GAP INBETWEEN EACH PARTICLE. IN THESE GAPS THERE IS AIR. WE THINK THIS BECAUSE WE CAN SQUASH THEM AND WHEN YOU POUR INTO A CONTAINER IT TAKES THE SHAPE OF THE CONTAINER.

GASES

WE THINK THE PARTICLES ARE THE SAME ALL THE WAY THROUGH BUT THERE IS A BIG AIR GAP INBETWEEN EACH PARTICLE WE KNOW THIS BECAUSE GASES ARE LIGHT AND ARE VERY SQUASHY. GASES ARE ALWAYS IN THE ATMOSPHERE AND YOU CANNOT COLLECT THEM IN A CONTAINER VERY EASY

The group have represented solids, liquids and gases in terms of particles. The distribution of particles in each phase has been decided upon by reference to 'ease of squashiness' of each. There are 'no gaps' in the solid structure but it is not continuous. The gaps in liquids and gases are filled with air.

The day after the group theory making lesson (6) Sharron was interviewed (T5B) about her developing ideas. The following exchange relates to the structure of gases.

Teacher:	What's in those gaps? (The gaps between the gas particles)
Sharron:	Mmm. [5 seconds] Actually with gases I don't know whether they have each individual particle. I don't know whether they have that.
Teacher:	What do you think there might be?
Sharron:	I think it might be just sort of - say this was a room - that was the whole particle of air. No gaps in between. No each individual particle.

An interesting turn of events! Although, on the previous day, Sharron had supported a particle model for a gap, she now expresses major doubts. Her ideas for a continuous gas are neatly expressed in terms of a particle that fills the whole room. At this point the teacher moves away from the role of neutral interviewer and intervenes to question the continuous gas model (would you be able to squash the gas if there were no gaps?) Sharron does not appear to be impressed ('yes, air is light and not very strong'). She appears not to feel the need to test or criticise her own theory.

An interesting question remains unanswered - why did she change her mind about the structure of gases?

During the next lesson (7) each group of students presented their own ideas as to the structure of matter to the rest of the class. Particle ideas were used by at least half of the groups and air was omnipresent between the particles. The teacher presented an argument (based upon his goldfish dying in pure distilled water!) in direct contradiction to the idea that liquid particles are surrounded by air. After the lesson, Sharron made the following diary entry:

> 'The lesson was very demanding but more or less going over what I already thought. It made me change my mind about in the between the liquid particles there is air. I was proved wrong from the story Mr. Scott told us about his goldfish. A good interesting lesson!

A further interview was held the next day (T6A).

Teacher: Where are you up to with your own thinking then? Are you still thinking about this?
Sharron: Yeah, em [laughing] I'm getting a bit confused with it now - the gas bits. What the gas is. And em .. you know I drew a diagram with .. em with liquids and put air gaps in [the group's poster].
Teacher: Yeah.
Sharron: That's made me sort of think. But now I think there's just gaps of nothing.
[The teacher asks Sharron to draw out her present models of solids, liquids and gases].
Teacher: What's that? [pointing at gas]
Sharron: Well I don't think gases are - have parts. I think they're just ... sort of ... whole and .. all just one big sort of shape.

The teacher questions this point of view and argues that, 'if particles are present in solids and liquids, then surely they will be present in gases'.

The teacher's argument is based upon his perception of the need for consistency within the model. The inclusion of continuous and particle ideas within a single model is at variance with his commitment to the need for internal consistency in a 'good theory'. The teacher is judging Sharron's theory according to his own epistemological beliefs (the standards by which he judges knowledge). Sharron, unfortunately, does not share these beliefs. She is not aware of the notion that scientific theories must be internally consistent.

Sharron states that gases are 'whole'. Presumably this is an expression of her belief that gases fill all of space. The problem is one of believing that gases can have empty gaps in them. Discussion reverts to what exists between the particles. (T6A).

Teacher: What do you think is between the particles in a liquid now?
Sharron: Nothing at all .....well I think there might be some sort of gas but not air - because what you said from - you know with the goldfish. So, there might be some sort of gas. Em, I don't know what sort of gas ... or just nothing.

Sharron is obviously not convinced about there being 'nothing' between the particles in a liquid. As with the structure of gases this remains a problem for her at this stage. The teacher returns to the structure of gases.

Teacher: Would it not be possible to say that as you go from a liquid to a gas - why can't you keep your particles and just have them even more spread out? So that as the kettle boils, then the water evaporates, it turns into steam and the particles are just further apart.

Sharron: Yeah, we'll stay with that idea, I think (2 seconds). But what baffles me is what's in between them.

The teacher is very direct in supporting the particle model and Sharron finally appears to acquiesce. The *crux* of the problem must surely lie in the statement 'what baffles me is what's in between them'. It is this question of what exists between the particles that is creating uncertainty for Sharron over the structure of both liquids and gases. That there is nothing between the particles can not be proven directly. Ultimately, belief in the existence of nothingness in air demands an act of faith (a metaphysical commitment) which runs counter to everyday experience of continuous liquids and gases.

Up to this point, the motion of particles in matter has not emerged. In order to introduce that concept the teacher demonstrated (lesson 8) gaseous and liquid diffusion. After the lesson, Sharron noted in her diary that 'these experiments proved the particles move and differently'. A few days later the teacher questions Sharron about particle motion in gases. (T6B)

Teacher: If you were to put on your microscopic spectacles and look at the particles in this room - what do you think you would see?

Sharron: Em .. well I think we'd get a lot near to us cos we keep breathing in so they'd be rushing towards us and then rushing out again when we breathe out.

Teacher: If you could pick out *one* of them which was away from where we're breathing - what would you see?

Sharron: Em, I think it'd be moving quite fast ...bouncing off other particles and bouncing against the wall and objects around.

When asked about 'the particles in this room' Sharron paints a realistic picture of the particles being carried to and fro by the tidal flow of breathing - a picture which contrasts with the teacher's idealised model. At this point in the interview, the teacher refers back to a statistic which has been quoted in the last lesson (9) - by one of the students.

'There are 50 million, million, million particles in a thimble of air'.

Teacher: Did you think we were talking about that kind of number?

Sharron: No I didn't think it'd be *that* much. I think it'd have been, em, more sort of this region here - that 50 there - not that other millions there [laughs].

Teacher: The spaces between particles are going to be absolutely tiny aren't they?

Sharron: Yeah, but they must be fairly big for them to move about so.

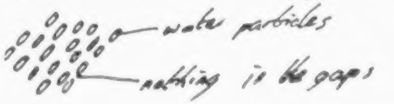
Sharron's response to the 'thimble statistic' indicates problems with grasping the scale of the particle model - it is *not* a 'microscopic view'. The gaps are relatively big yet unimaginably small. In retrospect it seems likely that part of Sharron's unease about there being nothing between gas particles has been due to her overestimating the size of the spaces. In this respect the static, idealised, particle drawings of gases are not helpful. Why should the student interpret them in any other way than literally?

The teacher now refers back to the particle motion and asks what keeps the particles moving. Sharron replies 'em .. I don't know what makes them move. Say you got a piece of paper - it don't move - unless its sort of pushed or blown'. She has apparently noted the difference between large objects which obey Aristotelian mechanics and need a push to make them move and particles which just keep going. This issue puzzles Sharron.

At the start of lesson 10, the pupils were set the task of individually sketching out the structure of pure water.

Pure Water

Inside it's made up of lot's of particles. Thease are microscopic. They are very tiny gaps inbetween. There isn't anything in the gaps



Sharron uses particle ideas, stresses the small size of the gaps, and makes clear that there is nothing in the gaps.

During lesson 11, the teacher reviewed the developing particle model with the class and started the pupils off on application activities. After the lesson, the teacher interviewed (T7A) Sharron and asked her about the nature of the particle ideas.

Teacher: What kind of information do you think this is? Do you think it's the truth? Or our class's ideas? Or what scientists believe? Or what do you think it is?..All this stuff about particles?

Sharron: Em .. just what people think ... em just an idea .. but I think, I think it has been approved.

Teacher: Well you say 'what people think' - but if you went up to the shops and stopped people coming out of the supermarket most of them would never have heard of particles.

Sharron: Ah, no ....it's a scientific sort of thing!

6. Theories of Conceptual Change: Issues arising from the Present Study

6.1 The Learner's Conceptual Ecology

Posner, Strike, Hewson and Gertzog (1982) have used the term 'conceptual ecology' to describe an individual's existing cognitive resources which influence the selection of a new conception. Consider aspects of the conceptual ecology in view of the case study data.

6.1.1 Metaphysical beliefs.

The case study relates to learning in a highly abstract and theoretical field. In particular, the student experienced difficulty in developing a particle model for a gas. Acceptance of the particle model involves a commitment to the notion of a vacuum existing between the particles and this notion may be counter to existing ideas. Furthermore, the existence of the vacuum can not be directly demonstrated and the student's existing ideas (e.g. air fills all of space) are equally inaccessible. As Sharron stated 'what baffles me is what's in between them'. Conceptual change in this situation does not involve a simple change of ideas but a revision of metaphysical commitments (fundamental beliefs about the nature of the world which by their very nature are immune from direct empirical refutation). Further examples, in the case study, of the influence of metaphysical beliefs are evident with the problem of scale of the pupils model - the gaps are unimaginably small; with the concept of particles being in a constant state of motion - what keeps them moving?; with the adoption of non-causal explanatory factors such as - 'all things assume their natural place.' As Hewson (1980) has pointed out, metaphysical beliefs are often implicit, with the person holding them unable to articulate them in any detail. As such, they can then constitute an unidentified barrier to greater understanding of the topic.

6.1.2 Epistemological beliefs

Hewson (1984) has described epistemological beliefs as the standards by which a person judges knowledge. An interesting mismatch of concerns between teacher and student arose during the case study when the teacher referred to the need for internal consistency in a scientific model and the student obviously did not share that epistemological belief. This resulted in a form of 'intellectual stalemate' in which a meaningful exchange of views on that particular issue was hampered by epistemological differences.

6.1.3. Metacognitive beliefs

Metacognitive beliefs are the learner's beliefs about his/her own learning. Although not referred to by Posner et al, such beliefs can certainly be considered to be part of the learner's conceptual ecology. In other words, a student will arrive in the classroom with beliefs about what is involved in the teaching/learning process. If the student's beliefs are counter to the ideas of the teacher then problems may well follow.

Throughout the lessons Sharron was able to reflect upon, and chart the progress of, her own thinking. Thus she could identify that she has been 'fitting all of her ideas together' and was able to isolate fundamental difficulties - 'what baffles me is...' Personal experience has shown that intellectual involvement of this nature is not common in 'ordinary science teaching'. A feature of constructivist approaches to science teaching lies in the importance which is attached to the exposure and subsequent development of student ideas. It is surely desirable, in terms of promoting meaningful learning, that the student should be aware of the rationale behind such methods and that, as part of the learning process, the pupil should be encouraged to reflect upon his/her own ideas. Ruddock (1986) comments that , for the pupil, 'all too often the curriculum is revealed day by day, like the tear-off sheets on a block calendar: rarely are they offered an explanation of the logic of particular courses of study.' Of course, explanations may not be enough. The student must construct for herself ideas about learning. The case study does, however, indicate that a child of little more than average ability is capable, when encouraged, of such reflection.

6.2 The Process of Conceptual Change

In some ways, 'conceptual change' seems an inappropriate title for what was observed during the study. Rather than conceptual change there appeared to be a parallel development of particle ideas alongside already existing ones. At the end of the teaching, Sharron was able to clearly differentiate between her 'life-world' and 'scientific' knowledge in stating that the former would be more useful in talking to her mother (who does not have a scientific background). The parallel development of ideas resulted in alternative explanations which can be employed as and when appropriate. There was no major conceptual change of the kind referred to by Posner et al (1982) as an 'accommodation'.

Nevertheless, it is possible to identify other changes which occurred during the development of the particle model. For example, Sharron initially was convinced of the notion that there must be air between gas and liquid particles. Her responses to the post-test questions suggest that finally she had changed her mind on this issue. It is interesting to note that this development of ideas, or conceptual change, took place over an extended period of time (a matter of weeks). There was a gradual evolution of ideas which was characterised by periods of uncertainty for the student. Such an evolutionary view of conceptual change has been identified by Nussbaum and Novick (1982) and Posner et al (1982). The teacher's story about his goldfish (lesson 7) was used to promote conceptual conflict over the issue of air between particles. The story suggests that air can not exist between the partcles of a pure liquid. Sharron acknowledged this 'fact' but the issue remained subject to debate for some weeks later. The case study thus raises doubts about the effectiveness of critical experiments/events which are designed to prompt conceptual change. Such 'discrepant events' have been employed by Nussbaum and Novick (1982).

Throughout the lessons and interviews, Sharron drew upon a wide range of ideas in attempting to make further sense of both those existing ideas and the developing model. Thus the particle model was invoked to 'make sense of' the behaviour of bacteria and the flow of steam was used as a means of understanding particle motion. Although some of these links were clearly inappropriate (in scientific terms) the link-making process appears to be important in cross referencing, testing and generally coming to terms with new ideas. Osborne and Wittrock (1985) have supported this point of view.

The teacher was impressed, and somewhat surprised, by the range and quality of Sharron's thinking. The organisation of the lessons plus the schedule of individual interviews allowed plenty of time for talking, and this resulted in the explicit consideration of many issues which the teacher had not previously encountered in twelve years of teaching particulate theory - which is not to say that those issues had been absent from pupils' concerns.

'What baffles me is what's in between them!'

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ANALOGICAL REASONING AND FORMALIZATION IN TRANSPORT PROCESSES

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Introduction

Analogy is an important tool in Physics, both in research and in teaching. It has an heuristic value,as well as explicatory power: in this respect it is widely used also by popular science writers. Some analogies, and their related concept, the metaphor, are so deeply rooted in our scientific thinking (as in the case of "waves" or in that of "fluxes") that we no longer perceive them as such.

Transport processes constitute a field in which analogy is widely used: "heat flow" and the hydraulic simulation of electric circuits are obvious examples. We have concentrated our research in this field, with the aim of understanding whether, and to which extent, analogy is a useful didactic tool, and how much the analogies that the teacher deems useful and significant are so also for the pupil.

Our frame of reference is that of alternative conceptions: we look for coherent frameworks in the explanations of analogous processes, both in relation with spontaneous and with scientific conceptions, and we try to understand if a suggested analogy is a sufficient marginal stimulation (in the sense of Vigotsky) to trigger a change from naive to more formalized thinking.

Bearing in mind the power and the elegance of Onsager's phenomenological relations(1), which give a unitary presentation for the Thermodynamics of irreversible processes, we have always treated, at introductory university level, processes of heat transport, electrical conduction, shear and bulk flow of real liquids and molecular diffusion in a compact presentation: we believe that the effort of abstracting a common schema of proportionality between a "flow density" and a suitable gradient should give a reward in helping to understand both meaningfully and economically such a large number of phenomenologies. This, however, does not seem to be generally the case. We observed in a previous paper(2) that, even at postgraduate level, analogical reasoning in transport processes (such as the analogy between induction of anaesthesia by gas inhalation and the charging process of a condenser) may be difficult to understand.

We gave first year and postgraduate students of the medical school a number of questions coverig different phenomenologies,(from the flow in a funnel to a case of stationary diffusion) at different degrees of complexity (from "true or false" items to the question of whether physical quantities such as "potential difference", "temperature difference", "electric field intensity", "power emitted by a heater","conductivity", "intensity of current", "fluidity" etc. could be classified as "forces" or as "flows").

The students' ability to answer correctly seemed to be strongly dependent on the content and on the format of each item. Very little coherence was present in the answers to problems which we considered as analogous, and no tendency to use simpler questions as guidelines for producing correct answers to more complex items became evident.

We realized that, in order to increase our insight into the cognitive processes in the above mentioned field, it was necessary to reduce drastically the complexity of the items and to be very careful when constructing rigorously analogous questions about familiar situations. We shall now describe a test composed of three pairs of items whith a rather low coefficient of difficulty for University students, and therefore apt to be also given to Junior High School pupils (14-15 years old). Another test, which has been given only to University students, will also be discussed.

THE QUESTIONNAIRES

The first questionnaire (see the Appendix) consists of the following pair of items: the first (T_1, T_2), asking the best position for a switch in an electric circuit and for a valve in a heatig system respectively, with a simple answer and the request for an explanation of the choice. The second (T_3,T_4), about the effect of a switch and of a valve, in similar situations as before and with multiple coice answers. The third (T_5, T_6), about the stationary flow of water in a funnel and of heat from a room. The items have been arranged in two different sequencies, by arranging the paralel questions either jointly or separately.

RESULTS: The test has been given to 22 University students of better than average ability (School of Dentistry) and to 63 Junior High School students of mixed ability.

The questions' order seemed to be uninfluent on the result and therefore their respective order was not taken into account in the analysis. On the contrary, different performances for the two items of each pair were evident even for the University students. In fact, while only 2 of these gave answer B to the first circuit question (T_1) (all the rest giving the correct answer C), in the case of the analogous question about the radiator (T_2) there were 5 A's and 2 B's. The second circuit question (T_3) received the following answers: 1 A, 3 B, 2 C and 16 D (the correct one), while the "valve and wheel " question (T_4) got a remarkable 8 E answers (from the 2 students who gave the parallel answer C to the other question and 6 more). It would seem as if the difference between the two phenomenologies, i.e. the liquid flow and the electric circuit, in which inertia is somehow related with the first but not with the second, prevailed over the similarities of the situations.

Finally, while all the students gave the correct answers to the questions about room temperature, the funnel questions received two pair of answers of the type "emptying" and "overflowing" while 8 more students gave the right answers with a wrong rationale ("the rate of flow from the funnel remains constant").

More striking are the inconsistencies in the answers of the Junior High School students (Tab. 1-3): the equivalence of X and Y position for the switch

TABLE 1: Contingency table for tests T_1 and T_2
(N.A. = no answer)

TEST T_1	TEST T_2 A	B	C	N.A.	Tot.
A	10	4	2	/	16
B	/	/	1	/	1
C	27	3	14	1	45
N.A.	/	/	/	1	1
Tot.	37	7	17	2	63

TABLE 3: Contingency table for tests T_3 and T_4

TEST T_3	TEST T_4 A	B	C	D	E	Tot.
A	3	/	/	/	3	6
B	2	2	/	12	21	37
C	/	1	/	2	3	6
D	1	1	/	8	4	14
Tot.	6	4	/	22	31	63

TABLE 3: Contingency tables for tests T_5 and T_6

TEST T_5	TEST T_6 A	B	C	N.A.	Tot.
A	3	14	1	/	18
B	/	37	1	2	38
C	1	3	/	/	4
N.A.	/	/	/	1	1
Tot.	4	54	2	3	63

	D	E	F	N.A.	Tot.
D	1	/	6	/	7
E	/	1	18	1	20
F	/	2	26	/	28
N.A.	/	1	7	/	8
Tot.	1	4	57	1	63

was recognized by 45 pupils whereas only 17 made the same choice in item T_2. 27 pupils answered "A" for the valve and "C" for the switch. For the "valve and wheel" question (T_4), 31 gave answer E (delayed stop) and only 22 the correct answer D. For the analogous circuit item(T_3), 37 chose B and 14 the correct answer D. Only 3, however, answered that both the wheel and the lamp had a delayed stop.

Not only inertia, therefore, but also the polar nature of electricity introduces disturbing differences between the two "analogous" problems.

For the stationary flow questions, many more pupils gave the right answer to the "room" case than to the "funnel" case, and about one fourth of the total gave the right answer for the room and at the same time the "emptying" and "over-flowing" answers for the funnel.

Another experiment was undertaken with a group of fifteen questions which combined different phenomenologies (water flow, electric current, heat flow etc.) with different logical structures (continuous or discontinuous flow regulation, conservation laws, series and parallel elements). With them we built four different questionnaires, two of them presenting analogous questions on different phenomenologies and the other two grouping the items according to the same phenomenology but not to the same logical structures. Each questionnaire was given to a group of about 25 medical students, and the results did not show systematic differencies between the alternative grouping, with rather poor performances in all cases.

Some open-ended questions, for which a good answer would require a certain degree of formalization, were approached only very trivially. For instance two questions regarding equilibrium under different forces required a simple vectorial approach, but only one student out of 50 gave spontaneously an answer of this type.

CONCLUSIONS

We may summarize our results in the following statements:

- our students are almost unable to employ analogical reasoning to solve similar problems regarding different phenomenologies in the field of transport processes.
- our students show a low tendency to formalize, even after taking courses where formal approaches have been repeatedly introduced.

If we recognize, with other authors(3), that analogy is to be found in the formal description and not in the bare phenomena, and if we recall, with Feymann (4), that "a remarkable coincidence helps the physicist to retain a broad knowledge of the physical world, precisely that the equations for many different physical situations have exactly the same appearence", we may then conclude that our students are unable to use analogical reasoning fruitfuly because they have not reached a sufficient ability to formalize.

If this is generally true, some corollaries should be important for the teaching practice:

First: analogies in general are useful only if they are accompanied by a formal presentation of the different phenomenologies:

Second: particular analogies can help introduce formal thinking either if they are very strict (a condition that, in practice, is very difficult to fulfil) or if particular attention is given not only to similarities but also to specific differences.

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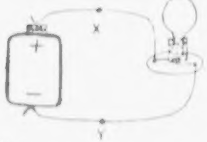
3. G. Ravagnan and G. Vettorazzo, La Fisica nella Scuola 19, 196 (1986)
4. R. P. Feynman, R. B. Leighton and M. Sands, "The Feynman Lectures on Physics", Vol. II, Chapt. 12 (Addison Wesley Pul. Co. Inc., 1964).

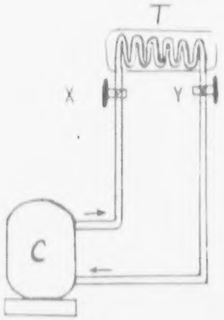
T$_1$ THE FIGURE REPRESENTS AN ELECTRIC CIRCUIT FORMED BY A LAMP AND A BATTERY. SHUOLD YOU WANT TO ADD A SWITCH, WHERE WOULD YOU RATHER PUT IT ?



A - IN X   B - IN Y   C - INDIFFERENTLY IN X OR IN Y

EXPLAIN YOUR ANSWER.

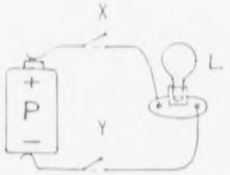
T$_2$ THE FIGURE REPRESENTS A SIMPLE HEATING SYSTEM: C IS THE BOILER, T IS A RADIATOR AND WATER CIRCULATES IN THE DIRECTION OF THE ARROWS. WHICH OF THE TWO VALVES X OR Y MUST BE CLOSED IN ORDER TO STOP THE FLOW OF HOT WATER WITHIN THE RADIATOR ?



A - X   B - Y   C - INDIFFERENTLY X OR Y

EXPLAIN YOUR ANSWER.

T$_3$ THE FIGURE REPRESENTS AN ELECTRIC CIRCUIT CONSTITUTED BY A BATTERY (P), TWO SWITCHES (X AND Y) AND A LAMP (L). INITIALLY BOTH SWITCHES ARE IN THE "OFF" POSITION AND THE LAMP IS UNLIT. WHAT HAPPENS IF WE PUT SWITCH Y IN THE "ON" POSITION ?



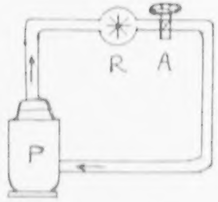
A - THE LAMP LIGHTS UP AND STAYS LIT BECAUSE THE ELECTRONS WHICH ISSUE FROM THE NEGATIVE TERMINAL REACH X.

B - THE LAMP DOESN'T LIGHT UP BECAUSE THE ELECTRIC CURRENT, WHICH IS SUPPOSED TO ISSUE FROM THE POSITIVE TERMINAL, STOPS AT X.

C - THE LAMP LIGHTS UP JUST FOR A SHORT TIME, BECAUSE THE CURRENT REACHES X AND THEN STOPS.

D - THE LAMP DOESN'T LIGHT UP BECAUSE NO CURRENT FLOWS THROUGH THE CIRCUIT.

T$_4$ A PUMP (P) CAUSES WATER TO CIRCULATE IN THE TUBE SHOWN IN THE FIGURE. THE WATER WHEEL (R) ENABLES YOU TO MEASURE THE AMOUNT OF WATER PASSING THROUGH. WHAT HAPPENS IF YOU CLOSE THE VALVE A ?



A - THE WHEEL R STOPS BECAUSE THE WATER REACHES THE VALVE AND THEN GOES BACKWARDS.

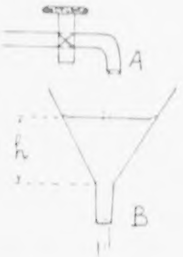
B - THE WHEEL R MOVES MORE SLOWLY BECAUSE THE WATER REACHES THE VALVE AND PART OF IT GOES BACKWARDS.

C - THE WHEEL R KEEPS MOVING NORMALLY

D - THE WHEEL R STOPS BECAUSE ALL THE WATER STOPS.

E - THE WHEEL R KEEPS MOVING FOR A SHORT TIME, UNTILL THE WATER HAS STOPPED COMPLETELY.

T$_5$ THE FIGURE SHOWS A FUNNEL FED BY A STREAM OF WATER. THE LEVEL IN THE FUNNEL IS CONSTANT BECAUSE THE AMOUNT OF WATER WHICH GOES OUT FROM B IS EQUAL TO THAT POURED BY THE TAP A. IF, BY MEANS OF THE TAP, THE STREAM IN A IS REDUCED A BIT, WHAT DO YOU THINK WILL HAPPEN ?



A - H DECREASES AND THE FUNNEL EVENTUALLY EMPTIES COMPLETELY

B - H DECREASES AND THE LIQUID SETTLES AT A LOWER LEVEL

C - H REMAINS CONSTANT, BECAUSE THE AMOUNT OF WATER GOING OUT FROM B IS ALWAYS EQUAL TO THAT ENTERING FROM A

IF, ON THE CONTRARY, THE TAP IS OPENED A BIT, WHAT DO YOU THINK WILL HAPPEN ?

D - H REMAINS CONSTANT, BECAUSE THE AMOUNT OF WATER ENTERING IN A IS ALWAYS EQUAL TO THAT GOING OUT FROM B

E - H INCREASES TILL THE WATER OVERFLOWS THE FUNNEL

F - H INCREASES AND THE LIQUID SETTLES AT A HIGHER LEVEL

EXPLAIN YOUR ANSWERS.

CRITICAL THINKING IN TEACHER EDUCATION PROGRAMS

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INTRODUCTION

Research on cognitive development has provided science educators with useful information regarding the wide variety of reasoning patterns used by students. Many curriculum specialists understood that students cannot grasp concepts which go beyond their intellectual capabilities or stages of cognitive development (Piaget, 1964; Flavell, 1977). Researchers also concentrated their attention on the learning process itself, on how students learn and on the factors influencing cognitive growth. It was found that children come to school with their own intuitive knowledge about the world and this intuitive knowledge often acts as a barrier to the acquisition of scientific concepts during the formal teaching/learning process (Driver et al., 1985; Pines, 1986; Osborne & Freyberg, 1985; Freitas, 1987; Duarte, 1987; Faria, 1987). As a result, scientific curricula were created taking into account the cognitive stages of the learners, their alternatives conceptions and their reasoning patterns. In fact, most recent science curricula worldwide have as objective the development of critical/logical skills. And if we accept that to be scientific literate means, among other things, to be able to think critically, that is, "the disposal of unsound proposals" (Cronbach, 1963), we have to conclude that it is of the utmost importance the avoidance of logical fallacies and the suspension of judgment when evidence is lacking.

Research on intellectual development of secondary school students shows that a large portion of secondary school students are concrete-operational (Friot, 1970; Karplus et al., 1975; Chiapetta, 1976; Sequeira, 1980). Research studies on teachers' intellectual skills are only a few but still indicate that "many of these teachers do not possess the reasoning patterns, which activity-centred science curricula seek to develop" (Garnett & Tobin, quoted by Jungwirth, 1985).

In this paper we will discuss the 8th and 10th grade students, student teachers, experienced teachers and university professors' capacity to avoid logical fallacies, in order to derive some important implications for the curricula of teacher education programs regarding the teachers' role in fostering students' cognitive development.

METHODOLOGY

Student, student-teacher, teacher and university professor samples were all drawn from the populations of these groups in the district of Braga. The student sample comprised 129 8th graders and 101 10th graders in five senior secondary schools. The student-teacher sample included 22 interns in secondary schools doing their internship, still under the supervision of faculty members of the university and a cooperative teacher in the school. The sample of experienced teachers (mostly tenured teachers) had 28 subjects selected from six secondary schools. And finally the authors obtained a small sample of 6 professors in the university where they teach. All teachers and professors as well as student-teachers were from the area of science education. Although the samples were not very large, they are regarded as representative of the populations concerned. Only the sample of university professors is too small to be considered representative of this group. The testing took place in the Spring of 1987.

All subjects answered to the research test Tami/1983 (Jungwirth, 1985) based on the following rationale:

"There are, in fact, three possibilities of subject-behaviour when confronted with a complex situation about which they are to offer an opinion, or to evaluate already formulated opinions and conclusions:

1. to analyse the given situation and correctly evaluate the offered opinions/conclusions in accordance with the situation's logical structure i.e. in a logically sound manner.

2. to analyse the given situation and incorrectly evaluate the given opinions/conclusions by accepting an opinion which constitutes a logical fallacy.

3. to ignore the logical structure of the situation and focus instead on its content or contextual aspects, leading to the acceptance of logically irrelevant and/or subjectively attractive, or seemingly plausible options" (Jungwirth, 1985).

The test consisted of 28 four-choice items, half of them related to biological subject-matter (BIO-items) and the other half related to non-curricular (everyday or school-life) situations (LIFE-items). Each item contained four options: one logically sound (logsound), one logically unsound (logfal) representing the logical fallacy and one or two content/context options. LIFE-items may contain a "neutral" response when reasons for choice were not called for. Respondents were expected to reject all the unsound arguments/conclusions in all the BIO-items. In all LIFE-items there was a logically sound argument/conclusion that was expected to be the one selected.

The test included eight logical fallacies which, when committed, invalidate scientific reasoning and therefore should be avoided as any modern science-curriculum suggests. After administering the test the authors of this study had to invalidate one of the fallacies (drawing conclusions on the basis of non-representative instances) due to errors of translation and missing words which altered the logical structure of the fallacy. Therefore, data referred to items 7, 10, 24, 27 were discarded.

The seven logical fallacies included in the test were:

a. Assuming that events which follow others are caused by them (post-hoc reasoning).

b. Drawing conclusions on the basis of an insufficient number of instances (sample too small).

c. Assuming that something which is true in specific circumstances is true in general.

d. Imputing causal significance to correlations.

e. Drawing inferences about individual cases from the mean of the population.

f. Drawing conclusions on the basis of very samll and fortuitous differences.

g. Explaining by use of tautologies (circular reasoning).

RESULTS

We present the data of two items - one curricular (BIO-item) and one non-curricular (LIFE-item) for each of the following four logfal categories. Total response data as well as the total test results are also presented.

1. *Post-hoc fallacy*

(Assuming that events which follow others are caused by them)

A) Item 21: curricular context (Table 1)

The food for a certain school's laboratory animals (rats, mice, etc.) was bought from a well-known shop. The animals were fed according to the instructions, but did not develop well, showed sign of tiredness, moved around slowly and some of them even died. The pupils decided to buy the food for the laboratory animals from a different shop from then on. Were they right ?

a. The decision is wrong, since it is not reasonable to think that a well-known shop would sell bad food.
b. The decision is reasonable - it is a fact that the animals died after eating the food supplied by this shop.
c. The decision is reasonable, since it is well known that food is very important for animal development.
d. I don't agree with any of these choices.

TABLE 1

Item 21 curricular context (BIO)

Results (%)	LS	LF	CC	N
8th grade (N=129)	16	22	60	2
10th grade (N=101)	31	24	45	
Student-teachers (N=22)	64	23	13	
Teachers (N=28)	47	46	7	
Professors (N=6)	33	50	17	

LS-Logsound; LF-logfal; CC-content/context; N-neutral/no response

B) Item 17: non-curricular context (table 2)

A new instructor prepared the school's athletic team for the annual regional sports competition. The team lost in almost all contests. In previous years the school had won in almost all contests. A group of pupils saw the principal and demanded that the former instructor should be invited to coach the school's team again next year. What is your opinion ?

a. The pupils probably did not take the training as seriously as they should have done, so the instructor may not be to blame.
b. If the school team succeded in all the previous years then the new instructor must be responsible for this year's failure.
c. The pupils were wrong. The fact, that the failure occurred after the change of instructors does not prove that the new instructor was to blame.
d. I don't agree with any of these choices.

TABLE 2

Item 17 non-curricular context (LIFE)

Results (%)	LS	LF	CC	N
8th grade (N=129)	55	20	16	9
10th grade (N=101)	66	16	10	8
Student-teachers (N=22)	59	23		18
Teachers (N=28)	43	32		25
Professors (N=6)	67			33

N-neutral (suspension of judgment or no response)

Table 3 contains the total post hoc results and Table 4 contains the percentages of logsound responses base on the total of logical responses (logsound+logfal only). In table 4 we can see the percentage of people who responded correctly to the logical structure of the situation (logsound) in relation to the number of people who responded logically, both correctly and incorrectly (logsound+logfal).

TABLE 3
Total post hoc results (%)

	curricular*			non-curricular*		
	LS	LF	CC	LS	LF	CC
8th grade	15	33	50	40	15	35
10th grade	21	28	50	51	18	22
Student-teachers	48	23	27	59	18	5
Teachers	50	29	21	57	16	2
Professors	50	25	25	58		17

* Neutral responses are not included

TABLE 4
Logsound responses based on logsound+logfal (%)

	curricular*	non-curricular*
8th grade	31	73
10th grade	43	74
Student-teachers	67	77
Teachers	63	78
Professors	53	100

* Neutral and content-context responses not included

2. ***Sample too small***
(Drawing conclusions on the basis of an insufficient number of instances)

A) Item 6: curricular context (table5)

Some high-school pupils bought two live fish from a pet-shop in town and decided to find out if this type of fish could survive in river-water. They filled an aquarium with water from the river near their school and put the fish in. The fish died after a short period.
What is your opinion ?

a. It is well known that rivers often carry poisonous substances and these might have killed the fish.
b. Some fish cannot live in sea-water and others cannot live in river-water. This explains what happened.
c. If these fish died in river-water it means that this kind of fish cannot live in that river.
d. I don't agree with any of these choices.

TABLE 5
Item 6 curricular context (BIO)

Results (%)	LS	LF	CC	N
8th grade (N=129)	7	43	50	
10th grade (N=101)	12	50	38	
Student-teachers (N=22)	41	27	32	
Teachers (N=28)	72	14	14	
Professors (N=6)	33		67	

B) Item 4: non-curricular context (table 6)

Two schools (A and B) arranged a mathematics contest. Two Standard 9 pupils from each school took part. School B won. School B's pupils concluded that the pupils in their school are better in mathematics than those in School A. What is your opinion ?

a. The pupil's conclusion is wrong, since one has to think not only about the pupils in a school, but also about the teachers.
b. Two pupils from a school are not enough for a comparison between schools.
c. The conclusion is correct, since school B won the contest.
d. I don't agree with any of these choices.

TABLE 6

Item 4 non-curricular context (LIFE)

Results (%)	LS	LF	CC	N
8th grade (N=129)	62	9	24	5
10th grade (N=101)	85	2	10	3
Student-teachers (N=22)	77	9	5	9
Teachers (N=28)	86			14
Professors (N=6)	33		17	50

The total "sample too small" results appear in Table 7. Percentages of logsound responses based on the total of logical responses (logsound+logfal only) appear in Table 8.

TABLE 7

Total "sample too small" results (%)

	curricular*			non-curricular*		
	LS	LF	CC	LS	LF	CC
8th grade	8	37	55	51	14	30
10th grade	10	41	49	72	3	20
Student-teachers	34	34	32	77	5	9
Teachers	57	23	20	86		
Professors	33	8	58	50		17

* Neutral responses are not included.

TABLE 8

Logsound responses based on logsound+logfal only (%)

	curricular*	non-curricular*
8th grade	17	78
10th grade	19	96
Student-teachers	50	94
Teachers	71	100
Professors	80	100

* Neutral and content-context responses are not included.

3. ***Generalizing from specific to general***
(Assuming that something which is true in specific circumstances is true in general)

A) Item 11: curricular context (Table 9)

A team of scientists was working to find a way to overcome a certain strain of bacteria, which causes a fatal disease in dogs. The bacteria were grown in the laboratory and treated with various chemicals until, at last, a chemical was found which killed this strain of bacteria. The chemical was then injected into a large number of dogs suffering from this disease, but the dogs did NOT recover and died. When the chemical was injected into healthy dogs, however, the dogs did not suffer any harm. What is your opinion ?

a. This is not surprising, since there are all sorts of chemicals, some stronger and some weaker.

b. This is surprising, since if a chemical kills these bacteria, it should also make the dogs recover.

c. This is not surprising, since diseases are caused not only by bacteria.

d. I don't agree with any of these choices.

TABLE 9

Item 11 curricular context (BIO)

Results (%)	LS	LF	CC	N
8th grade (N=129)	23	37	38	2
10th grade (N=101)	23	50	26	1
Student-teachers (N=22)	59	41		
Teachers (N=28)	71	21	4	4
Professors (N=6)	17	33	50	

B) Item 8: non-curricular context (Table 10)

The teachers in a certain school (school A) decided to improve pupil's achievement, by doubling the amount of their daily homework. Pupil-achievement, however, became worse than before. Another school (school B) tried the same thing, the pupil-achievement there become much better than before. What do you think about this ?

a. The results are not surprising, since what is true in one place need not be true in another.

b. The results are surprising, since if an increase in homework reduced achievement in one school, it is not logical that it should do the opposite in another school.

c. The results are not surprising, since what counts is not the amount of homework, but how hard the pupils study.

d. I don't agree with any of these choices.

TABLE 10

Item 8 non-curricular context (LIFE)

Results (%)	LS	LF	CC	N
8th grade (N=129)	4	10	86	
10th grade (N=101)	6	4	90	
Student-teachers (N=22)	27	5	68	
Teachers (N=28)	21	4	68	7
Professors (N=6)	17		66	17

The total "specific to general" results appear in Table 11. Percentages of logsound responses based on the total of logical responses (logsound+logfal) appear in Table 12.

TABLE 11

Total "specific to general" results (%)

	curricular*			non-curricular*		
	LS	LF	CC	LS	LF	CC
8th grade	20	22	55	20	13	63
10th grade	19	32	49	29	8	61
Student-teachers	55	28	16	43	7	46
Teachers	70	18	11	40	6	45
Professors	25	25	50	34	9	50

* Neutral responses are not included

TABLE 12

Logsound responses based on logsound+logfal only (%)

	curricular*	non-curricular*
8th grade	48	61
10th grade	38	79
Student-teachers	66	86
Teachers	79	88
Professors	50	80

* **Neutral** and content-context responses are not included.

4. ***Differences too small to be meaningful***
(Drawing conclusions on the basis of very small and fortuitous differences).

A) Item 25: curricular context (Table 13)

Some pupils did the following experiment in order to find out about germination of seeds in different soils:
100 sunflower-seeds each were sown in two large flower-pots, Pot A contained soil from the mountains, pot B soil from near the coast. The two pots were kept under the same conditions. After 10 days the number of seedlings was found to be: In pot A - 69, and in pot B - 72. What do you think ?

a. The results were to be expected, since it is a known fact that soil from the coast is more fertile.
b. It is difficult to decide, since germination is also influenced by temperature and moisture.
c. The experiment shows that soil from the coast is more suitable for the germination of sunflower seeds than mountain soil.
d. I don't agree with any of these choices.

TABLE 13

Item 25 curricular context (BIO)

Results (%)	LS	LF	CC	N
8th grade (N=129)	12	38	46	4
10th grade (N=101)	13	58	29	
Student-teachers (N=22)	27	59	14	
Teachers (N=28)	68	21	11	
Professors (N=6)	50			50

B) Item 23 non-curricular context (Table 14)

Two soccer teams met for the cup-final which was played on a neutral sports-ground. Team A won. The results were five goals to four. what is your opinion ?

a. Team A is the better team, since it beat team B even on a neutral ground.
b. It is impossible to say which team is the better team, the difference in points does not prove it.
c. Team B probably did not try hard enough, so it deserved to lose.
d. I don't agree with any of these choices.

TABLE 14

Item 23 non-curricular context (LIFE)

Results (%)	LS	LF	CC	N
8th grade (N=129)	47	16	23	14
10th grade (N=101)	60	12	16	12
Student-teachers (N=22)	68	14		18
Teachers (N=28)	54	18	7	21
Professors (N=6)	50			50

The total "differences too small" results appear in Table 15. Percentages of logsound responses based on the total of logical responses (logsound+lofal) appear in Table 16.

TABLE 15

Total "differences too small to be meaningful" results (%)

	curricular *			non-curricular*		
	LS	LF	CC	LS	LF	CC
8th grade	11	25	63	34	25	27
10th grade	12	38	50	46	24	21
Student-teachers	18	41	41	62	23	7
Teachers	55	18	27	44	13	15
Professors	34	42	24	50	9	9

* Neutral responses are not included.

TABLE 16

Logsound responses based on logsound+logfal only (%)

	curricular*	non-curricular*
8th grade	31	57
10th grade	24	66
Student-teachers	31	73
Teachers	76	77
Professors	45	85

* Neutral and content-context responses are not included

The total test results (across logfals) appear in Table 17.

The total logsound results (based on logsound and logfal only) appear in table 18.

Table 19 presents the mean scores on total test results in all seven fallacies (life and bio-items), considering the logsound responses given by each subject.

TABLE 17

Total test results (across logfals) (%)

	curricular*			non-curricular*		
	LS	LF	CC	LS	LF	CC
8th grade	14	35	50	36	21	32
10th grade	17	37	45	50	16	26
Student-teachers	41	32	27	63	14	12
Teachers	58	21	19	59	10	12
Professors	33	32	35	47	6	18

* Neutral responses are not included

TABLE 18

Logsound based on logsound +logfal only (%)

	curricular*	non-curricular*
8th grade	29	63
10th grade	31	76
Student-teachers	56	82
Teachers	73	86
Professors	50	89

* Neutral and content-context responses are not included

TABLE 19

Mean scores on total test results (all seven categories)

	BIO	LIFE	BIO+LIFE	BIO/LIFE
8th grade	1.62	4.26	5.88	.49
10th grade	2.07	5.94	8.01	.44
Student-teachers	4.86	7.54	12.40	.85
Teachers	7.00	7.10	14.10	1.00
Professors	4.00	5.66	9.66	.70

logsound=1; logfal, content-context and neutral=0

To test the significance of the mean scores on total test results in all seven fallacies (life and bio-items) of the subsamples (student and teacher groups) as shown in table 19, a one-way analysis of variance was performed, showing that the means are significantly different from each other and indicating how each group performed on all categories of the test (seven fallacies).

The statistics were as follows:

BIO: F-ratio = 38.861, p<.001

LIFE: F-ratio = 21.282, p<.001

BIO+LIFE: F-ratio= 46.816, p<.001

BIO/LIFE: F-ratio = 3.749, p<.005

DISCUSSION AND RECOMMENDATIONS

The analysis of data allows us to make some conclusions:

a) on curricular items (BIO-items) there is a significant difference between the reponse patterns of all groups. Generally, 10th grade students got a better score than 8th graders, student-teachers got better scores than students. All secondary school teachers performed better than all the other groups, including the small group of university professors, whose results, due to the size of the sample (N=6), should be interpreted with caution (Tables 17, 18, 19).

b) On non-curricular items (LIFE-items) there is also a significant difference between the response patterns of all groups, although this difference is not as Sharp as in the case of the curricular items (BIO-items) (tables 17, 18, 19).

c) on LIFE-items mean-scores were roughly three times higher than BIO-scores in the students' groups, while the student-teachers scored twice higher in LIFE-items than in BIO-items. Teachers scored similarly in both BIO and LIFE items (Tables 17, 18, 19).

d) It seems to exist a tendency in all groups, especially in BIO-items, to give responses in a content-context situation. This trend decreases from 8th grade students to secondary school teachers. We can even say that the groups' performance in a content-context situation for both BIO and LIFE-items is inverse (Table 17).

In summary, it seems that this study corroborates other authors' findings about the cognitive development of both students and teachers. On the other hand, evidence points to the fact that student-teachers (and teachers) are not aware of these problems and studies like these are essencial to bring about teachers' awareness of the existence and the magnitude of the problem as well as to recognize the intellectual skills as prerequisites for the profession and as a desired outcome for their pupils.

It seems that the development of teacher-skills in the domain of critical thinking should be an objective of any science-teacher education program. Teachers should see themselves as facilitators of learning and not as agents of knowledge transfer. They should become more concerned with the teaching/learning of all dimensions of science (content, process, history of science and interaction science-society) as well as with the development of skills which are demanded by modern science curricula. Concurrent with these concerns is the problem of the evaluation of the students' performance still done by summative methods and mostly content-oriented and requiring pupils to function at the lowest levels of Bloom's taxonomy. It is obvious, and research has showed it over and over again, that this is not the way the educational community will help to shape the XXI century generation. It is a tremendous job for the teacher education institutions and if we fail we cannot expect to solve the problems that humanity is already facing.

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Introducing Concept Mapping in the Day to Day Science Curriculum

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The purpose of this study was to introduce concept mapping and several other techniques into the day to day science curriculum of a "typical" classroom in a British Columbia junior secondary school. Previously we had successfully utilized concept mapping within a highly modified curriculum which was based upon a constructivist philosophy. This more recent work was an attempt to utilize concept mapping within the context of the regular science curriculum and thus to investigate the efficacy of these methodologies in the normal, day to day science curriculum. Our research can be categorized as classroom based action research as described by Hopkins,(1985). Our general objectives were:

1. To introduce concept mapping and to develop students' skills in producing concept maps as described by Novak and Gowin (1983) and further to develop some practical and "user friendly" methods of evaluating concept maps which might prove to be useful to other science teachers.

2. To utilize a number of other innovative strategies in order to promote a more reflective, constructivist and therefore, a less transmissive learning environment, while at the same time, continuing to follow the normal curriculum.

3. To produce a set of video tape exemplars which could be used both in preservice and inservice education of teachers and to share these products with other teachers.

4. To determine and deal with the constraints faced by a teacher and the students who are being faced with the dilemma of teaching curricula which is ever widening in its scope, within a finite period of time.

5. To utilize concept maps as part of the total student evaluation in science classes.

6. To attempt to develop in students a greater awareness as to how knowledge itself develops and becomes known and meaningful to each of us. Our project attempted to promote thinking and questioning in a more open and a somewhat less teacher-centered, less transmissive environment.

7. To encourage students to feel free to question knowledge that is presented, ex cathedra, by the textbook and by the teacher.

8. To implement these constructivist strategies within a regular junior secondary school science class with "average students".

9. Finally, the project attempted to utilize the thoughts and ideas of the teacher and the students in order to promote spontaneous reflection and subsequent investigations based upon ideas that were felt to be worth a "follow-up". This "reflection in action" strategy has been described by Schon(1983).

Subjects:

A class of 26 students was selected for this study

by approaching the science department head and requesting a "typical-average" grade eight class for our study. These students (16 girls and 10 boys) ranged in age from 13-14 years. Students had already been taught most of the units from Science Probe 8 (Buller et al, 1985) published by John Wiley and Sons, (a new text series which had been written to implement British Columbia's recently revised Junior Secondary Science Curriculum). The students had been taught previously by the science department head, whose style, by his own admission was generally highly transmissive, with some key labs taught by somewhat "open" investigation. This teacher was also generally highly regarded and perceived as a very effective teacher. These students, therefore, were used to covering a great many topics at a high rate of speed.
Students were on a five by eight, nonsemestered, rotating timetable and therefore did not meet every day - which can be regarded as an impediment to continuity, and intellectual engagement with the subject matter.

The Teacher and Co-Researchers:

The teacher who took over the class for the purposes of this study was known to the students as the school's vice-principal, and also a member of the science department. As the study took place from mid April until the end of May, many of the students stated that although they enjoyed their former teacher, they appreciated having a different teacher, simply as a novel change. The researchers, Professor Gaalen Erickson, and doctoral candidates Sharon Parsons-Chapman and Allan McKinnen were introduced to the students. The researchers attended all classes, observing and recording procedings by means of video and audio tapes and written notes. Very soon after beginning the new unit of instruction, the visitors became an accepted part of the classroom environment.

Procedures:

Prior to beginning the study, permission was sought from administration and parents. The consent letters seemed to generate a considerable amount of interest which helped to create a positive response disposition among the students. In the letter we outlined only very broadly the objectives of our study and we asked for parental consent and cooperation. We also informed

parents that we may be asking them to provide us with data on a voluntary basis.

Prior to beginning the actual unit of study, students were told of the general plan that we had for the unit. They were informed that the unit would be presented in a different form. The teacher attempted to convince the students he was genuinely interested in their ideas, thoughts, and questions and that he was interested in determining what the students already knew about the subject matter. Moreover, the teacher informed the students that he was most especially interested in students realizing what they themselves had learned from the unit. Students were told that the concept mapping technique was a powerful tool that could help them organize their thoughts and ideas - therefore several introductory lessons had to be devoted solely to teaching the technique.

Scope and Sequence:

Teaching Concept Mapping Technique:

A considerable amount of time and effort was devoted to teaching the skill of concept mapping. Four lessons were completely devoted to this aim. In the first lesson, the teacher introduced concept mapping by having students provide him with the living, the nonliving and the events surrounding the topic of "school". Students, being experts on the topic, readily volunteered concepts which were categorized under these headings:Events, Living and Non-living. Together the teacher and the students linked the components with verbal propositions. An arrow, showing the direction of the linking statement was always included. At this time, an outline of only the concepts was given to the students who were then asked to try to link them together in their own way. A list of statements was placed on the overhead projector for those students who were experiencing difficulty getting started. In the second lesson, the students and the teacher made part of a concept map together, for the topic of "pets". This topic was selected because it was thought that students felt very knowledgable about the subject and would volunteer information and also show ownership of the concept map quickly. This topic indeed proved to be very workable. Again concepts were elicited from the students and organized under the general categories of : Events , Non-Living and Living. These categorizations seemed to be very helpful to students. A teaching sequence similar to lesson one was follwed, but in lesson two, students had to provide their own linking propositions. Maps were checked by the teacher and assistance given.

Introducing the Pre-unit Concept Map:

Students were introduced to the unit, "You and the Natural Environment". At this point they were told why they were being asked to make a pre-unit concept map of "nature". Again, students were encouraged to use the categories of "Living, Non-living, and Events" as well as "Thoughts, Ideas and Questions" and any other categories that they found to be helpful.

Students were told to finish the concept map on nature as a homework assignment. They were specifically challenged as well to put themselves in the concept maps on nature. During this class period, one of the students made a remark of a metaphorical nature which caused the teacher to spontaneously discuss the idea of metaphor and consequently, students were encouraged as well to include a metaphor of nature on their concept map. In the initial concept maps, "Nature" was seen to be:

"...a killing ground, a cathedral, a mysterious place, a mating ground, farm grounds, a sporting place, a resting place, a camping place, a factory, a resource, a poisoned place..etc." Students were also asked to try to teach one of their parents or guardians how to concept map using the pet or school model. These students were also asked to try to convince their parents to make their very own concept map on nature so that the research group and the students themselves may learn from the experience. Eleven students complied with the request. Pre-unit concept maps were collected and assessed.

Teaching the Unit: "You and the Natural Environment":

This unit attempts to provide children with basic environmental literacy. The following topics are presented in the unit:

-Survival("Planning a Wilderness Camp-out")
-Hypothermia
-"The Mini-Ecosystem"
-"The Food Web Game"
-Computer Simulation Games (Odell Lake and Odell Forest)
-Trophic Structure
-Niches and Habitats
-Mid Unit Quiz
-"Relationships"
-Pyramids of Numbers and Biomass
-Introduction to the Natural History of the Area
-Biomapping
-Unit Review ("Tie it Together")
-Final concept map on nature
-Final Examination of unit

Preliminary Findings:

Modification of Lessons Within the Unit in order to Promote Reflection and Thinking:

Throughout the unit, attempts were made to promote our objectives. For example, in the "lesson" (actually a sequence of lessons), on building a mini- ecosystem, in which students constucted a self-contained ecosystem in a 4 litre jar containing sand, a snail, a small goldfish, and aquarium plants - the lesson was modified somewhat. As written in the text, students were to constuct the ecosystem, monitor it and answer a set of interpretive questions one week later. This lab activity as it was written in the text, already lent itself perfectly to our purposes. We further modified it to promote student thinking by asking students to complete fairly detailed logs each day. Student logs were categorized under the headings of:
Date- Things I Noticed-Questions and Thoughts.

Students were told that this lab was especially important and that we were very interested in not only their observations but especially the questions and thoughts that the ecosysem fostered. Prompts such as "I still wonder about, I wonder why, I wonder if", etc. were given to assist students with the last category.

Members of the research group were impressed by the amount of effort and interest shown by the students in this particular activity. The resulting logs (student journals), provided the group with a wealth of data much of which is worthy of follow-up investigations:

1. Students seemed to able to apply the terms "abiotic and biotic" to most events in their mini-ecosystem.
2. Many students did not seem to realize that the gases in the mini-ecosytem were part of the abiotic component of the system.
3. Many students did not on their own, realize that "energy" travelled to the fish from the sunlight via the green plants, in spite of the fact that "The Food Web Game" was done concurrently with the mini-ecosystem activity. Some correctly stated that energy went directly from the sun to the fish in terms of warmth (thermal energy) - a point not mentioned in the text.
4. Some did not see the plants as gas (Oxygen and Carbon Dioxide) makers.
5. There was a need to deal with the mistaken presumption in the text that students knew much about Oxygen and Carbon dioxide. The gases were seen by one student as coming directly from the sun. Air and oxygen were used interchangeably. The global term "air" was often used in an undifferentiated manner.

6. Oxygen was even confused with fish food!
7. Many students felt comfortable enough to admit in their labs, "I don't know why...happened."
8. Questions about the size of the fish and the size of the container were seen in terms of "roominess and comfort" questions rather than as questions of limitations of supply of the necessities for life. One student in particular stated however, that "...smaller fish need less of everything to survive and that is why we used them in our small system."
9. Anthropomorphic conclusions were abundant: The fish was described as "friendly", "lonely", "accepting its surroundings","enjoying being watched" etc. One student's observations in particular, while quite creative, were largely of a human-social nature. All students named their fish and became quite emotionally involved with them. Many took them home at the end of the unit.
10. Often the sex of the fish was presumed; "he or she" was used throughout the students' observations.
11. The role of bacteria was not understood by some students in the breaking down of wastes. Bacteria, wastes and algae were often confused.
12. Many students speculated as to the cause of death when their fish died..ie water quality, disease in the water, prior condition of the fish, etc.
13. None of the students on their own made comments on the recycling of nutrients in their mini-ecosystems.
14. Some students asked many thoughtful questions, a few of which were subjected to further experimentation. Some interesting questions were:
(a) "Why are we putting the lid on the jar?"
(b) "Won't the fish die with the lid on the jar?"
(c) "Do fish play?"
(d) "Just because an animal is seen eating does it mean that it is getting energy from the food?"

Assessing Concept Maps:

Utilizing the general advice provided by Novak, early concept maps were assessed. Novak encouraged readers to"...experiment with their own scoring keys and refinements of scoring criteria." (Novak, 1984, p.108). Early maps were assessed by awarding points for raw number of valid concepts, for number of valid links and for numbers of valid cross links. Much difficulty was experienced by the teacher in using this system to arrive at a numerical index which he felt was a valid reflection of the worth of the concept map. Counting up the numbers of valid concepts and connections did not appear to reflect the worth of concept maps, as some students made more profound maps with fewer statements than other students who may have had many correct terms and connections that were correct but much more pedestrian and obvious. After attempting to score the maps, the teacher told the students that he would discuss the maps with each student, but that students were to ignore the numbers on the maps as these represented his first attempt to score maps. As written feed-back to students, early maps were simply graded as good, satisfactory or unsatisfactory.

Students were told that their final concept maps would contribute towards their report card grade for the term. In teaching, necessity indeed is

the mother of invention; the teacher was forced to grade a large number of post-unit concept maps quickly, prior to the final exam and in a manner that would be acceptable both to himself and the students. The teacher felt that a general impression should be formed by the marker utilizing a number of predetermined marking categories and that a mark out of ten should be awarded for each category. Accordingly, marks were awarded under each of the following categories:

Fluency and Completeness of Concepts.....	/10
Originality	/10
Organization and Conceptualization.......	/10
Connections, Cross-connections and Applications of Concepts to Daily Life...	/10
Ownership................................	/10
Total Score..............................	/50

The teacher felt that this simple method while still incorporating many of the suggestions given by Novak, was sufficiently practical that classroom teachers could find it useful. The reader may recognize a "creativity" component in this scheme. Another innovation is the term "ownership" which was used to indicate how much the student incorporated and reconciled his/her first concept map within the final concept map and also to what degree the student included his/her own real world experiences rather than just repeating the textbook and teacher exemplars. The concept map score was given nearly equal weighting to the final examination in the evaluation of the unit. The only evaluation problem of significance faced by the teacher was the fact that the unit had raised the marks of several students who were already destined to repeat the course. Scores on the final exam compared favorably with scores on the concept maps. A statistical comparison has not yet been made.

Some Constraints Faced by the Teacher in Utilizing Constructivist Techniques:

During the unit the teacher was faced with a dilemma. How does one teach expeditiously and at the same time allow for the serendipitous effects which arise while employing constructivist methodologies? Certain students were concened that the class was "falling behind the other classes". Indeed, the other grade eight classes which were taught in a transmissive style "covered" three chapters of material to our one. Time seemed to be the enemy of the constuctivist teacher who is trying to follow the regular currriculum. For example, in a discussion about herbivores, carnivores and omnivores, several students asked very profound questions about the teeth of these animal groups. The teacher happened to have a skull collection at his disposal - the result was yet another unscheduled lesson on "mystery skulls", perhaps one of the highlights of the unit. Students asked questions such as, "Why are bears considered carnivores when they are often omnivores, eating what is available during the season?"...and "Maybe polar bears are carnivores ,but black bears in the spring are almost herbivores." These were excellent points! The teacher welcomed such questions about the "dogma" that was being taught. Indeed, the ecological terms used in trophic structure are worthy of very close examination.

It takes time to examine knowledge, to reconcile incongruities, to design experiments and to re-adjust our thinking. Clearly transmissive teaching has great appeal to teachers who are faced with "covering" twenty six chapters of eighth grade science in one hundred hours or less. In many jurisdictions, the teacher is directed to "complete" the busy syllabus. The problems of limited teaching time coupled with an over-loaded curricula are indeed real and must not continue to be ignored.

Another problem that the teacher faced was the amount of teacher directed discussion that arose because of his desire to mark and fully discuss the assignments rather than simply marking them and returning them with minimal discussion which is often the case in the classroom. Although the teacher set out to not be "center stage", by his own admission, far too much time was spent in this mode.

Video Tape Exemplars:

To date five videos are being produced. The preliminary titles of the videos are:

Introducing Concept Mapping - Lesson One
Introducing Concept Mapping - Lesson Two
(these videos are suitable for pre-service teachers)
Introducing Concept Mapping in the Day to Day Classroom
(this 12 minute video is suitable for inservice sessions)
Interviews with Students about their Concept Maps
Making the "Final - Post-unit Concept Map"
(these videos may be of interest to graduate students

Student Reaction to the Study:

Students and parents were very supportive of our project. One student who was working on her project in the library (using reference books on her own to expand her map) told the librarian that she, ..." really did not like science before, but that now I am really enjoying it because of the way that we are learning it!" This positive feeling about the unit probably contributed to the very good test results that were shown by the class on the standard unit test. Upon completion of the final examination, students also completed an anonymous questionnaire about the unit. Twenty-five students submitted a questionnaire which rated eight categories on a ten point scale. The questionnaire results, summarized below, show the order of the students' preferences:

Rank.	Topic	Mean	S.D.
1.	The Mini-ecosystem lab and log	9.4	1.2
2.	Natural history (lab outside)	9.0	1.25
3.	This Project	8.98	1.25
4.	UBC staff	8.8	1.23
5.	How we did this unit	8.48	1.19
6.	Listening to each other	8.3	1.30
7.	Nature Studies	8.1	1.14
8.	Concept Mapping	7.7	1.97
9.	Listening to the teacher	7.44	1.97

Conclusion and Summary:

This preliminary report indicates that this project is worthy of more detailed scrutiny in a full case study. As it stands, the teacher feels confident that concept mapping does work well in a pre-post unit situation in the regular curriculum. Concept mapping proved to be a valuable tool in assessing student progress both formatively and summatively. These students who were of average ability, generally enjoyed the unit as it was presented and enjoyed having their thoughts, ideas and questions accepted by fellow students and adults in the classroom. By listening to what our students were saying, we discovered that there is a great deal of presumed knowledge in the introductory ecology unit. We suspect that the same kind of problem exists from unit to unit. Students, were mistakenly assumed to know more than they did about "energy" and gases such as Oxygen and Carbon Dioxide, etc. (The corollary is also likely to be true - that transmissive teachers fail to establish and recognize those meaningful understandings that students bring to the class prior to classroom learning.) Students particularly enjoyed the mini-ecosystem lab with

its log-journal approach. Students did indeed question the dogma in the discipline and did find some "holes" in it and did begin to come to grips with the idea of knowing. Student concept map-making skills improved dramatically, but only one preliminary concept map, ie "pets" or "schools" would have been sufficient to teach the skill at the onset. Although the normal curriculum was followed, we did embellish it considerably because of our constructivist methodologies. Consequently our students did fall behind the other classes who were learning in a direct, transmissive, positivistic environment. Finally, the teacher felt that he did develop, at times, a "reflection in action" teaching style that produced some interesting insights into the topics that were investigated.

The teacher recommends these reflective, constructivist techniques, but suggests to those teachers who are forced to "instruct" in a highly regulated system with its concommitant busy curriculum, should select at least one or two important units for trial teaching with the types of constructivist methodologies such as concept mapping and log-journal approaches to laboratory work. It is this teacher's opinion that a plethora of, regulated, high speed instruction may obstruct genuine science education in many classrooms.

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Misconceptions of Experts and Novices during a Genetics Computer Simulation

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A computer simulation, CATLAB, was selected as the principal vehicle with which to examine subjects' genetics concepts and problem solving strategies as they interacted with a model of a genetic population. CATLAB (Kinnear, 1982) was designed to complement conventional genetics instruction. The program enables students to select traits, hypothesize about gene interactions, and decide which cats to cross. The traits students can investigate with CATLAB include coat color, amount of white spotting, density of pigment in the fur, distribution of pigment in the fur, tabby striping, and the presence of a tail.

Using a familiar organism such as the domestic cat provides a common experience to which learners may link their perceptions and understanding of "real world" genetics to classroom genetics (Kinnear, 1986). Experiences with CATLAB may help learners clarify concepts they previously did not understand. For instance, students using CATLAB are required to examine, organize, and analyze data for patterns. They may recognize, identify, and extract data patterns which signal the characteristics of particular inheritance principles.

The selection of CATLAB was based upon several criteria: the open-ended nature of the program was conducive to an inquiry laboratory format; the program was based upon a valid scientific model; most individuals have had common experiences with cats; and the program represented exemplary software that was available.

CATLAB (Kinnear, 1982) served as the interactive medium for studies of learners' concepts and problem solving strategies. The simulation required learners to :

1. generate their own question(s);
2. apply scientific principles;
3. decide which parameters or variables to contol;
4. gather, record, analyze, and interpret data they generated;
5. draw conclusions to support or reject hypotheses.

Structured Observations

A naturalistic research methodology provided the framework for the research design of this investigation. The principal objective of the study reported here was to identify genetics concepts and misconceptions of subjects during problem solving with CATLAB. Videotape recordings of subjects' interactions with CATLAB were the primary source for verbal protocols for this investigation (Krajcik, Simmons, and Lunetta, 1987; Simmons, 1987). An Apple IIe microcomputer was connected to the video output of a videocassette recorder. This technique permitted the simultaneous recording of subjects' comments about their perceptions, observations, predictions, and explanations with the video display from the computer monitor.

The CATLAB activity was centered around a learning cycle model of exploration-invention-expansion phases (Renner, Abraham, and Birnie, 1986; Simmons and Lunetta, 1987). Subjects explored genetic traits in cats by selecting characteristics and generating offspring during exloration and invention phases. During the expansion phase, all subjects investigated a given hypothesis: determine the inheritance pattern of the orange tabby striping trait.

Research Subjects

The research subjects participating in this study included a sample of experts and a sample of novices. All three experts held a Ph.D. in a science field, conducted research within the area of genetics, and taught a course within the interdisciplinary graduate program. The ten novices were high school students (volunteers) from Advanced Biology courses.

Results

A number of misconceptions about genetics principles surfaced during subjects' interactions with CATLAB during their investigation of the orange tabby striping trait. Transcripts of verbal commentaries from videotape recordings revealed misconceptions such as:

1. Punnett square probabilities represented the outcomes for four offspring (most prevalent misconception)
2. incomplete dominance or co-dominance meant approximately equal numbers of offspring with the same phenotype;
3. the most numerous phenotype of kittens generated from crosses between cats of different phenotypes was the dominant trait;
4. a cross (between two cats of different phenotypes) resulting in kittens with only one phenotype meant the kittens' phenotype was the dominant trait, and the parents must be homozygous dominant;
5. dominant and recessive traits could be heterozygous.

The misconceptions about basic principles, such as inheritance and probability, implied that the majority of subjects operated on non-scientific explanations with which to make decisions, to give rationales for those decisions, and to explain experimental data. When confronted with unexpected or discrepant data to analyze and interpret, they did not consider all possible explanations. One specific example was the interpretation subjects made of Punnett square probabilities.

One unsuccessful novice (subject 5) exhibited difficulties with the interpretation of probability and the relationship of the probability of gamete combinations to the Punnett square model. In particular, he experienced difficulty explaining discrepancies between the expected data for one offspring (based on the Punnett square) and the actual experimental data (produced by CATLAB). Subject 5 pursued reasoning based on the Punnett square probabilities until the experimental data matched or approached the expected data. He compared expected and predicted ratios and generated kittens until the outcomes from each litter matched the Punnett square predictions. The subject recorded each outcome and dismissed those outcomes which did not correspond to the Punnett square probabilities.

Subject 2 (unsuccessful novice) attemped to determine which phenotype was dominant by formulating various hypotheses. At first, he assumed blotched was dominant and proceeded to cross cats based on that assumption. As he generated more kittens, he became unable to discern a pattern from the data and subsequently changed his hypothesis to fit the data. His use of the terms "dominant" and "recessive" reflected misunderstandings of their meaning. The subject viewed dominance as a characteristic wich changed from generation to generation. He also misinterpreted the data and concluded that there were no apparent patterns of dominant or recessive phenotypes. The data did reveal patterns fitting descriptions of simple dominance inheritance.

One successful expert (subject 11) interpreted the data he generated (kittens) as evidence for independent assortment. He drew conclusions after generating large samples of kittens. The subject concluded hypothesis testing by explaining quantitative relationships and basing his conclusions on the mathematical relationships emerging from the data.

Another successful expert (subject 12) verbalized expected ratios, interpreted actual ratios, and mentioned the idea of sampling error when explaining the data.

> The subject repeated a cross between two orange mackerel kittens (F1 x F1) six times. He concluded: "now have 16, of which 9 are blotched and 8 are mackerel, like a 1:1 ratio with sampling error, apparent that blotched recessive to mackerel...1:1 ratio is reasonable, although sample size is small".

An unsuccessful novice (subject 7) interpreted the term "dominant" as the most numerous offspring of a certain phenotype. The subject repeated crosses using the same parents to investigate the genetic trait. The subject maintained the hypothesis that mackerel was dominant to blotched throughout the investigation.

Subject 8 (successful novice) based his reasons for selecting particular crosses on the choice of a specific phenotype of cat, to see if the same results would occur, to generate a larger sample size, and to "make sure this wasn't a fluke". This subject investigated the inheritance pattern using one set of assumptions about the dominant and recessive character of the trait. As he interpreted the data using these assumptions, he realized that the data did not support his conclusions. The subject then used an alternate set of assumptions, analyzed the data from that perspective, and arrived at valid conclusions.

> The subject completed crosses between orange mackerel and orange blotched cats. He verbalized: "results are conclusive, results are blotched trait dominant over mackerel. Discovered that mackerel v. blotched, mackerel female and blotched male yielded a 3:1 of blotched to mackerel. When blotched and blotched mixed, hold on a second please, making a chart here. If we assume the blotched is dominant, then those 3 would all be blotched, that doesn't work, oh no, that would mean all mackerel would have to have a double recessive trait, right?...2 mackerels can produce a blotched. That would lead me to believe that blotched cat would have the dominant-recessive trait, Dd, for example... I've got conclusive results, I just don't know what they mean...let's say blotched is recessive. That would mean, when we mix blotched and mackerel, the mackerel would come up with ratio of 3:1, but if that particular mackerel I created was Dd v. dd, that would do it, yes, the mackerel I originally produced was Dd...that means when you mixed 2 blotched cats, you get nothing but blotched cats. When you mix 2 mackerels, get mackerel to blotched in ratio of 3:1...I've got it, that explains it".

In an earlier pilot study, two unsuccessful novices (high school students) generated litters of kittens while switching inconsistently from invesitgating one trait to investigating another trait. They typically commented upon unusual (unexpected) kitten phenotypes and pusued several traits as they appeared in the litters. Their results led them to conclude the traits they investigated were co-dominant or incomplete dominant traits. They defined the inheritance pattern of co-dominance as equal numbers of kittens with the same phenotype.

The findings about variations in concepts used by the groups of experts and novices were generally consistent with results reported in earlier studies (Stewart, 1982; Smith and Good, 1984). Within the group of experts, variations in the use of genetics terminology were observed. For instance, the experts typically exhibited greater sophistication in the range of specific genetics concepts verbalized during hypothesis testing than did the novices. However, the experts also verbalized misconceptions. In particular, the experts reported here compared the actual ratios of kittens with the expected ratios or crosses (referring to Punnett square probabilities). They presumed that the outcome from one litter of four kittens represented the predictions of the Punnett square probabilities for one offspring. One expert generated a large sample and compared actual and predicted ratios of outcomes. This expert (subject 11) analyzed accumulated data through an appropriate application of the principles of probability. When large samples of offspring are generated, "classical" ratios (3:1, 9:3:3:1) of predicted phenotypes emerge. When small sample sizes are generated (one or two litters), these ratios may or may not emerge from the data patterns. The outcome from one litter of four kittens represents four independent events (four Punnett squares), not one independent event (one Punnett square).

The novices also exhibited misconceptions about the Punnett square and the nature of probability. This indicated that novices had an inaccurate understanding about the nature of probability and did not interpret and apply probability principles correctly to the data (kittens) generated.

Implications for Science Teaching

A principal concept underlying all genetics principles is the idea of probability. An examination of learners' ideas on the nature of probability from various perspectives (such as "everyday", mathematical, or an application activity) may add information on how individuals relate probability in different contexts. Such comparisons of learners' concepts of probability and their applications of the principles of probability to different situations may reveal significant variations in the level of understanding and their ability to transfer ideas to new situations or learning experiences. This information about learners' ideas and understanding of probability has signficant implications for the design of approrpriate curricula and the use of instructional strategies by teachers.

Many students have serious misunderstandings of concepts in genetics after completing conventional instructional units (Stewart, 1982). Using a simulation, such as CATLAB, enables teachers to help students confront misconceptions during learning. Students can redefine their questions and test new predictions and ideas.

Teachers should provide opportunities for students to experience and to investigate concepts through more meaningful and intellectually appropriate learning experiences. In addition, students should justify their explanations and be confronted with alternate views of data or ways of generating solutions to problems. By interacting with students and probing the reasoning behind their hypotheses and interpretations, teachers can promote the use of alternative approaches to guide students in successful problem solving and concept use and interpretation. Thus, teachers can become more responsive to their students' individual learning styles and characteristics. Such information could help teachers identify concept formation and interpretation and problem solving behaviors characteristic of successful or unsuccessful problem resolution.

Teachers should attempt to diagnose students' concepts and interpretations to determine the learner's use of strategic knowledge and the rationale driving the use of that strategic knowledge. Unsuccessful problem solvers may have overlooked specific cues within the data patterns or may be unable to extract pertinent or subtle cues from observations. The data from this investigation indicated that subjects interpreted data and underlying patterns within their framework of scientific explanations.

Whenever misconceptions about genetics principles surface while students interact with CATLAB, the teacher can confront students about discrepancies between their concepts and more scientific concepts that better explain the data. The teacher can suggest that a student pass through a learning cycle or parts of a learning cycle several times, each time, redefining questions, testing improved or new hypotheses, and drawing more valid conclusions based on their data.

Implications for Further Research

An array of research studies is needed to enhance understanding of the role of concept learning and misconceptions during learning. Such analyses can aid our understanding of how learners develop important scientific concepts and misconceptions.

The qualitative data reported in this study suggest that a more comprehensive set of studies are warrented. An intensive series examining the development of genetics concepts and concept interpretation across a range of learners at various levels of courses may provide additional information about learners' concept development. An examination of the formation and evolution of concepts and misconceptions as learners progress from "novice" to "expert" status or from unsuccessful to successful problem solver may provide more insight into cognitive structuring and restructuring. An extension of this study should incorporate a longitudinal study focussing on the evolution of mental models of learners at various levels of expertise. Using information about how learners construct and modify their cognitive structures and mental models during learning enables teachers to provide optimal learning experiences and environments which stimulate the formation, growth, and evolution of their students' mental conceptual schema.

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A DESCRIPTION OF STUDENT PROBLEM-SOLVING PERFORMANCE ON REALISTIC GENETICS PROBLEMS

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> There is wide acceptance that one important goal of education is to give students experience in solving problems. If this is accepted, then it is necessary to deal with problem solving, and not just with solutions. (Moore, 1986)

Introduction

Moore's statement, in a report on education for the American Society of Zoologists, underscores the importance of the current emphasis on problem solving as a valuable educational goal. The desire to improve student problem-solving performance has led researchers to study learning and problem solving in science disciplines. These researchers have investigated: how knowledge is acquired and integrated with previously learned knowledge; the processes used to solve problems; and how solvers' knowledge is related to their problem-solving processes. The goal of these researchers is the development of methods to improve student problem-solving performance (Stewart 1985).

This paper is a report of a study aimed at developing a description of student problem-solving performance in genetics. The problems that students solved were realistic problems generated by the microcomputer simulation GENETICS CONSTRUCTION KIT (GCK), developed by Jungck and Calley (1985). The knowledge of student performance gained in this research should be useful in developing genetics instruction for high school students.

Problem-solving Research in Physics and Genetics

Physics

Early research in problem solving involved identifying general and discipline-specific strategies used to solve problems in quantitative sciences such as engineering thermodynamics (Bhaskar & Simon, 1970), math (Greeno, 1978) and physics (Larkin & Rainard, 1984; Larkin & Reif, 1979). These researchers demonstrated that general problem-solving strategies were not sufficient for successful problem-solving performance. Rather, they demonstrated that large amounts of well organized discipline-specific conceptual knowledge and discipline-specific strategies, in addition to general strategies, were required.

In an effort to improve problem-solving instruction and performance in physics, Reif (1983) compared the problem-solving performance of physics experts with that of novices. He identified two types of knowledge required to solve physics problems as content knowledge and strategic knowledge. He divided content knowledge into three types: concepts and principles; knowledge of how to use these concepts; and a hierarchial structuring of this knowledge. He has also divided strategic knowledge into three types: data redescription to limit the problem space; solution synthesis to plan and complete a solution; and solution assessment to confirm a solution.

Genetics

Cause-to-Effect Problems

Problem solving in physics has been studied extensively and has served as a model for research in other disciplines, including transmission genetics. That genetics has been studied is not surprising since it provides a unifying theme for biology, especially evolutionary theory; serves as the basis for agricultural breeding programs and tracing human genetic disorders; is included in nearly all high school biology curricula (Hurd, Bybee, Kahle, & Yeager 1980); and is considered by high school teachers to be an important part of biology that students find difficult to learn (Finley, Stewart & Yarroch, 1982). In addition, problem solving is an essential part of genetics instruction and is one of the few areas in the high school biology curriculum where students are expected to solve problems.

Much of the research on learning and problem solving in genetics has focused on textbook problems. These problems provide all of the necessary information for a solution and typically require students to reason from cause (underlying genetic mechanisms) to effects (prediction of phenotype and genotype ratios). Figure 1 includes an example of a typical effect-to-cause textbook problem. The data for these problems is static, and because their solutions can be obtained by using algorithms, a correct answer doesn't necessarily measure a student's understanding of genetics (Longden, 1982; Stewart & Dale, 1981). In fact, students may have multiple, including erroneous, models of processes such as meiosis that they use to account for their problem solutions (Stewart & Dale, 1987).

Figure 1 Here

Effect-to-cause Problems

Textbook. Researchers have also studied problem-solving performance on textbook problems that are of the effect-to-cause type. These problems require a solver to reason from effects (phenotypes) to causes (the genetic mechanisms responsible for the phenotypes of individuals). To obtain solutions to these problems a solver is required to analyze data. Using problems of this type Smith and Good (1983; 1984) distinguished between successful and unsuccessful problem-solving performance by compiling a list of 32 general heuristics (rules of thumb). They observed that the strategies that best characterized the performance of successful solvers included seeking a solution rather than an answer, checking for consistent logic, approaching a problem working forward, checking for one variable at a time, and looking for evidence that would invalidate previous assumptions. Smith (1986) has also studied the solving of pedigree problems. He observed that unsuccessful solvers tended to model an instructor's solution without understanding underlying concepts, were dependent on expected ratios, failed to consider alternative hypotheses, were unable to assign genotypes to individuals according to their hypotheses, and changed hypotheses without substantiated reasons. Figure 1 contains an example of a problem used by Smith & Good.

Hackling (1984), in an attempt to understand more about genetics-specific problem-solving strategies, has described the performance of experts and novices solving pedigree problems. Figure 1 contains an example of a pedigree problem used by Hackling. The genetics-specific strategies that he identified included: identifying cues in the pedigree that were specific to the inheritance pattern; considering alternative hypotheses; and deliberately assigning genotypes to individuals. In a related expert/novice study, Hackling (1986) found that while experts did not differ from novices in the number of correct solutions for problems, they did provide a substantially greater degree of proof than did novices. Experts also, when compared to novices, identified more critical cues about genetic mechanisms, generated and tested hypotheses, were aware of the necessity to falsify alternate hypotheses, and recognized the need to modify strategies based on problem conditions.

Computer-generated. Other researchers have studied problem-solving performance with computer generated problems. These problems differ from pedigree problems in that the solver, in addition to interpreting data, is required to generate it. Kinnear, Martin, and Novak (1982) contended that genetic simulations allow students to practice reasoning skills that traditional labs or textbooks did not. Kinnear

(1983), using the computer simulations CATLAB and BIRDBREED, established the necessity for students to integrate their conceptual knowledge of genetics with genetics problem-solving processes in order to develop successful problem solving strategies. She noted that students who were successful at solving textbook problems were often unsuccessful at solving simulation problems. She also observed that unsuccessful solvers evidenced trial and error strategies, failed to recognize conclusive data, and reached solutions without confirmation or consideration of alternative hypotheses. Kinnear concluded that, while computer simulations make it possible to offer students experiences to develop strategic knowledge, simply having access to such a learning environment will not of necessity improve problem-solving skills. Kinnear (1983; 1986) makes a strong case for developing instruction that couples concept knowledge of a discipline with general and domain specific problem-solving strategies.

As an initial step in designing instruction in genetics problem solving, Collins (1986) has adapted Reif's model of desired performance (1983). By describing the performance of experts solving computer-simulated genetics problems produced by GENETICS CONSTRUCTION KIT, she identified both general and genetics-specific problem-solving strategies that they used. She described the genetics-specific strategies in terms of data redescription, solution synthesis, and solution assessment. Experts redescribed data in order to limit the problem space and to define the essentials of the problem. Their redescription statements included comments about the name and number of traits and variations, noting least or most frequent phenotype, observing missing classes of phenotypes and noting missing classes by sex. She also found that experts redescribed data at the beginning of a problem to formulate a hypothesis and at times during a solution when they changed hypotheses. Hypothesis generation and testing was the solution strategy used by experts.

Hypotheses fell into two categories--general hypotheses about inheritance patterns, and specific hypotheses about variations in one cross. In an effort to provide further support for their hypotheses, experts chose individuals to cross based on their redescription and hypothesis. Throughout the solution to a problem, experts worked back and forth between data and hypothesis. Solutions by experts were always confirmed, most often by generating additional data to explain their hypotheses. By combining a description of experts' problem solving with a rational analysis of the same problem classes, she produced a model of desired performance for solving specific classes of genetics problems. From these descriptions of expert performance, implications for instruction in genetics problem solving can be made. However, in addition to this model of expert performance, it is also important to identify the thought processes and knowledge that novices (students) use to solve similar problems.

The Study

The purpose of this study is to describe the problem-solving performance of high school students solving realistic genetics problems generated by GENETICS CONSTRUCTION KIT (GCK).

Students

Twelve high school students solved sixty problems while thinking aloud. These students, in grades 10-12, had completed three weeks of genetics instruction in an introductory level biology course. Students were selected by their teacher to represent different ability levels and grade levels, and because they were judged likely to talk aloud as they solved problems.

Problems Used in this Research

The problems used in this research were produced by the computer simulation (GCK). GCK is a simulation program that provides students opportunities to develop strategies for solving cause-to-effect problems in which the behavior of organisms is simulated. Specifically these problems were produced by a record-keeping version of GCK. The problem generator program presents the problem as an initial field collection of imaginary diploid organisms in which the females are homogametic and the males are heterogametic. Figure 1 includes an example of an initial field collection. The population is generated within parameters set by the researcher and is first displayed as an abbreviated list of individuals by phenotype and sex. In addition to the abbreviated list, the solver has access to an expanded version of the initial field collection which includes the names of body parts (traits) and of adjectives describing the body parts (variations). The problem generator produces a unique problem, within the parameters set by the researcher, each time a problem type is selected. For example, in simple dominance the program, by mimicking meiosis, randomly selects one of two alleles at a single locus and selects which allele will be dominant. The number of offspring produced from each cross is also within a predefined range set by the researcher. The solver must plan experiments, make crosses, interpret data, and arrive at a solution. A solution involves identifying the number of traits and variations of a trait and mapping genotypes to phenotypes.

The problems considered for analysis include monohybrid simple dominance, dihybrid simple dominance, and monohybrid co-dominance. The problems were selected to be consistent with the genetics that the students had been taught.

Data Gathering

Each student solved problems for two fifty-minute class periods. During problem-solving sessions, the researcher asked questions, encouraged students to think aloud and to explain what they were doing and why. Questions asked by the researcher included: "You seem to be thinking about..."; "Is that what you thought would happen...?"; "You're hoping for...?"

Each student was asked to solve one monohybrid simple dominance problem for practice in order to: assure familiarity with GCK; establish rapport with the researcher; and allow them to become comfortable with thinking aloud. After the practice problem, students were asked to solve additional monohybrid simple dominance problems as well as dihybrid simple dominance problems and monohybrid co-dominance problems. Figure 2 contains a tally of the number of each problem type attempted by each student. All students solved at least one problem of each type.

Figure 2 Here

Two types of research data were collected: problem data and tape recordings of the student thinking aloud. The problem data consisted of computer recordings of the initial population, individuals selected for crosses, and offspring produced.

Data Analysis

Transcriptions of the tapes from the problem solving sessions were analyzed in terms of initial population redescription, cross data redescription, hypothesis generation, crosses performed, solution synthesis, and solution confirmation.

The problem-solving transcripts were first organized to correspond to crosses that the students had performed. Problem solutions were then subdivided into frames, with frame zero representing comments about the initial population data. Each cross and any comments made about that cross constituted an additional frame. Each frame was analyzed for evidence of student performance corresponding to the performance categories described above. Following two readings of each transcript, data were collapsed and presented in three ways: a summary description of each student solving problems of each type; a summary description of student performance for monohybrid simple dominance, dihybrid simple dominance and monohybrid co-dominance problems for all students; and generalized descriptions about student problem-solving performance. It is this latter category that will be the focus of the following discussion.

Results and Discussion

Student performance was evaluated in terms of comments made about the initial field collection, plans or strategies used to make crosses and generate data, interpretations of cross data, and solutions and confirmation of solutions.

Redescription of the Initial Field Collection

Students' redescriptions of the initial field collection consisted of reading data from the computer screen. Frequently, comments were made about the least or most frequent phenotypes. Often these statements reinforced a misconception that the most frequent variation was the dominant variation. In addition, students attended to potentially misleading information in the initial field collection such as slightly unequal numbers of males and females of a certain phenotype. This latter observation often led students to conclude that sex linkage was operating in the problem. In general, students did not appear to understand that a field collection only represented a sample of a larger population and, therefore, only provided them a starting point for solving the problem.

Crosses

When students did not take advantage of what they knew from the field collection or did not define a goal for the problem, crosses were performed on a trial and error basis. The basic strategy for simple dominance problems, both monohybrid and dihybrid, was to cross two individuals with the same (like) phenotypes just to see what would happen. Ultimately, the students' hope was to reveal the recessive phenotype by accidentally crossing two heterozygous individuals. While this strategy eventually worked in the simple dominance problem, students who attempted to use it in the co-dominance problems became confused and invented explanations (such as co-recessive or double dominant) for the patterns in the data. A co-recessive or double dominant explanation involved using 3 letter symbols to represent 3 phenotypes, as though there were 3 alleles. For example, in 1 co-dominant problem, the 3 letters M (missing), I (inverted) and E (expanded) were used to represent 3 phenotypes. A cross between two M individuals produced offspring of 3 phenotypes M, I, & E therefore suggesting two phenotypes were recessive to the third.

A common cross strategy involved crossing all possible combinations of parents. This strategy was adopted in an effort to collect a large data set which could then be grouped into obvious patterns. Another strategy was to repeatedly cross the same individuals in an effort to establish some consistent pattern in the data or to provide some validity for what the student was thinking about as the inheritance pattern. In addition, most students repeatedly used individuals from the initial population as parents. This latter approach illustrated a lack of generational thinking, i.e., students failed to realize the potential of knowing the exact heritage of the organisms they were crossing.

Cross Interpretation

Cross interpretation usually began with students reading the names of the parents and offspring in a cross. Often this process was done to consolidate data or to look for numbers in the data that would fit with a known, and expected, ratio (for example, 3:1 which would indicate a cross between heterozygotes). Cross data interpretation did not necessarily help students plan or predict the results of the next cross. Several missed or unwarranted inferences about the cross data were common and caused students to change their interpretation about which variation was dominant or recessive. Common examples of these inferences included:

1. crossing two individuals of the same phenotype and producing all offspring of one phenotype and then concluding that the phenotype was either dominant or recessive;
2. crossing two individuals with different phenotypes and producing only offspring with the same phenotype and not recognizing the dominant variation;
3. crossing two individuals with the same phenotype and producing offspring of two variations without recognizing that the parents were heterozygotes or that the offspring genotypes were known.

These kinds of cross interpretations caused students to change their solution about which variation was dominant or recessive, as if each cross was a separate problem. Alternatively, when a student was firmly convinced of the dominance relationship and conflicting information emerged in the data, the information was often ignored or considered incorrect (for instance, the student would assume that a mutation had occurred). In addition the missed and unwarranted inferences illustrate that the students lacked an understanding of the problem at a genotypic level and failed to recognize the need to work within the consistent framework of a hypothesis or goal statement in order to structure a solution.

Solutions and Confirmation

Students generally confirmed their solutions about what phenotype was dominant or recessive by repeating a cross that supported their ideas. Occasionally, they would use a Punnett square drawing to help explain the inheritance pattern and, at times, ratios were used to confirm what they believed. However, these ratios were usually considered for one cross only and the data had to fit exactly or the solution would be discarded.

Summary

In summary, most students did not take advantage of what they knew about the problem from the field collection, and they did not think in generational schemes which would enable them to infer the genotypes of the parents used in a cross. Generally data were generated haphazardly rather than by establishing an hypothesis and generating a series of crosses to test the hypothesis. The missed and unwarranted inferences about cross data was evidence that most students think about problems on a phenotypic rather than a genotypic level.

While these descriptions were typical for the twelve students studied, other students of similar abilities and experiences are also being studied to further generalize these claims. The research data currently evaluated is consistent with that reported here.

Since the use of computer simulations in genetics and other sciences will undoubtedly continue to increase, critical questions still need to be addressed regarding computer use in science education. These questions include: "What are the appropriate uses?" "What are the instructional values?" and "What are the potential learning outcomes for students?" The evidence is clear. Simply providing an environment in which students are presented realistic genetics problems to solve is not sufficient to elicit good problem-solving skills. Therefore, an important potential learning outcome for students who use computer simulations, improved problem-solving skills, is not automatic. Problem-solving instruction in genetics will require that explicit connections between the content of the discipline and domain-specific strategic knowledge. Students must be coached to qualitatively redescribe initial data as well as cross data, to generate and test hypotheses, and to confirm solutions.

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Figure 1

Examples of Problem Types

Textbook Problem

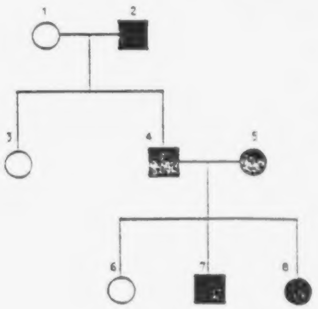
In humans six fingeredness is dominant to five fingeredness. What are the offspring, genotype and phenotype possibilities from a cross between one parent that is heterozygous for finger number and a second parent that is five fingered.

Textbook Effect-to-Cause Problem (Smith and Good 1983; 1984)

In chickens and other birds, the chromosomal basis of inheritance is the opposite of man; i.e., in birds, XX individuals are males and XY individuals are females. In chickens barred plumage is dominant to nonbarred plumage; the gene is sex linked. Suppose that you were a poultry breeder and that you needed large numbers of barred males and nonbarred females. Describe a breeding stock that you could assemble for this purpose which would produce only barred males and nonbarred females. Be certain that you show the genotypes of both the roosters and hens in your breeding stock and also the genotypes of all the offspring which this stock will yield.

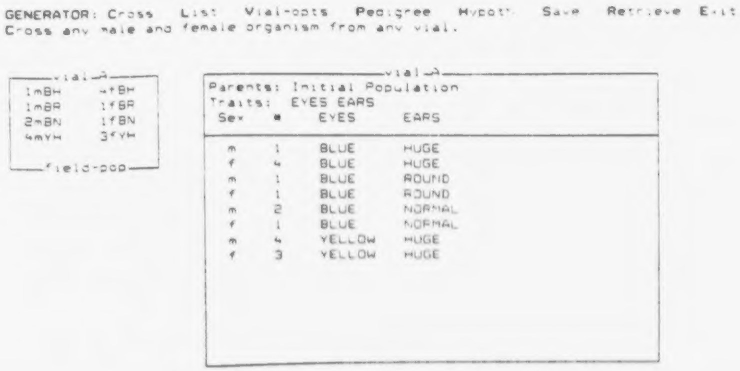
Pedigree Effect-to-Cause Problem (Hackling 1986)

This pedigree shows the inheritance of a common trait. Individuals affected with the trait are shaded, males are indicated by squares and females by circles. Your job is to determine the mode of inheritance of the trait. Provide as complete and conclusive an answer as you can.



Computer generated Effect-to-Cause problem (CGK-Jungck and Calley 1985)

Sample GENERATOR Screen



```
GENERATOR: Cross  List  Vial-opts  Pedigree  Hypoth  Save  Retrieve  Exit
Cross any male and female organism from any vial.

-----vial A-----
 1mBH    4fBH
 1mBR    1fBR
 2mBN    1fBN
 4mYH    3fYH
-----field-pop--

---------------------vial A---------------------
Parents: Initial Population
Traits:  EYES EARS
 Sex   #    EYES     EARS
------------------------------------------------
  m    1    BLUE     HUGE
  f    4    BLUE     HUGE
  m    1    BLUE     ROUND
  f    1    BLUE     ROUND
  m    2    BLUE     NORMAL
  f    1    BLUE     NORMAL
  m    4    YELLOW   HUGE
  f    3    YELLOW   HUGE
```

TYPES OF PROBLEMS SOLVED

Problem type	Description	Distribution
Monohybrid simple dominance	25, 1 trait problems simple dominance inheritance no modifiers	12 students solved 25 problems 2 solve 1 7 solve 2 3 solve 3
Dihybrid simple dominance	17,2 trait problems simple dominance inheritance pattern at both loci no modifiers	12 students solved 17 problems 5 solve 2 7 solve 1
Monohybrid co-dominance	18, 1 trait problems co-dominant inheritance pattern; no modifiers	12 students solved 18 problems 1 solves 3 4 solve 4 7 solve 1

Figure 2

PRIMARY TEACHERS' MISCONCEPTIONS ABOUT LIGHT AND SHADOWS

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Teachers in the elementary grades have been telling us for some time in surveys (Welch, 1981) and case studies (Stake and Easley, 1978) that they feel unprepared and uncomfortable with the science content they teach. They also have been telling us that they don't allocate much time for science (Schmidt & Buchmann 1983; Rosenshine 1980) and rely heavily on a text book when they do teach it, (Pratt, 1981).

Recently, researchers have turned their focus to the content and structure of teachers' subject matter knowledge and its uses in teaching. Buchmann (1983) proposed several ways in which teachers' content knowledge could affect teaching - in recognizing student answers which are wrong, for example; in maintaining the smooth and organized flow of the lesson; or in providing multiple, valid entry points into the content. Shulman (1986) described several kinds of subject matter knowledge, ranging from the substantive content to knowledge of children's misconceptions in a particular domain. In mathematics, Leinhardt and Smith (1985) have looked carefully at teachers' knowledge and how that knowledge influences teaching and children's understanding. High knowledge teachers, for example, provided students with multiple representations and heuristics, and had richly interrelated conceptual frameworks for the fractions domain. Low knowledge teachers in the same domain had fewer links among categories of problems, and could sometimes state the algorithm but not apply it.

In science education, especially in the elementary grades, studies of teachers' content knowledge have revealed similar findings. Teachers often hold some of the same misconceptions and have some of the same difficulties in understanding that their students do. For example, Apelman (1984) reports that some of the primary teachers with whom she worked thought of shadows as concrete entities. She provides a detailed and helpful description of their frustrations and problems in working with light and color activities.

The translation of science content during teaching, a form of what Shulman (1986) calls pedagogical content knowledge, is equally problematic. Classroom observations of science teaching suggest that teachers may limit the scope of activities and discussions, when their own knowledge is weak (Dobey and Schafer 1984). They may include discussions but generate misleading metaphors (Smith & Sendelbach, 1982), or be unable to use examples to clear up students' confusion in lessons (Roth, Anderson and Smith, 1986). On the other hand, skilled teachers have a rich and easily accessible store of examples and counter-examples with which to challenge student thinking (e.g., Collins & Stevens, 1982).

This paper reports part of a larger study of primary teachers' knowledge and its influences on teaching science lessons. In it, I want to look carefully at ten primary teachers' knowledge of the physics content in a unit on light and shadows, how that knowledge influenced their teaching, and how their knowledge came to change with time. The focus here is on teachers' knowledge of the physics content. We have reported elsewhere (Smith & Neale, 1987) the influences of their philosophical stance towards science and science teaching (syntactic knowledge); their knowledge of children's thinking and misconceptions; and their knowledge and use of conceptual change teaching strategies in science. All of these are critical to successful elementary science teaching. Yet, one of our main concerns was to understand the teachers' thinking about the physics content and to support their construction of content knowledge, so that they, in turn, could use that knowledge to generate the needed examples, explanations, representations and metaphors in their teaching.

Method

We worked with ten primary teachers who were recruited from three local school districts. They all had at least five and up to twenty-seven years' experience and ranged in age from mid-twenties to mid-fifties. All have been given feminine pseudonyms.

Prior to the four-week program, in June, 1986, each teacher was individually interviewed about the physics content of the light and shadows unit. The interview took place in a clinical interview-about-instances format, in which word problems with drawings were presented and teachers drew, then explained their answers; answers were probed in order to clarify teachers' thinking. In this way, we hoped to gain a clear picture of each teacher's own understanding of the content, so that the light and shadows activities would provoke conceptual change where needed.

In the first week of the program, teachers read and discussed research on children's misconceptions (e.g., excerpts from Piaget 1972; Eaton et al 1984; DeVries n.d.) and on teaching strategies which facilitated conceptual change (e.g., Anderson and Smith 1983a). In addition, they explored their own knowledge of light and shadows in activities aimed at revealing their own misconceptions and facilitating their own progress in understanding the content. Readings and activities were designed to meet Case's (1978) suggestions for instructional design and incorporated the conceptual change teaching strategies which we hoped they would learn (Anderson and Smith 1983a). At the end of the week, they conducted clinical interviews with children who were coming to the summer camp.

In activities about light and shadows, lessons with teachers were organized around the central problems they had revealed in their own clinical interviews. Lessons opened with a problem or puzzle to explain; proceeded to predictions, reasons, explanations and debate from the entire group; led to activities in which they sought solutions with a peer and represented their results in some way (writing, graphs, tracings, etc.); and ended with discussion of their ideas, previous predictions and explanations, unresolved problems, and so forth. Having other adults express misconceptions and difficulties in understanding (e.g., one teacher who, for several days, could not understand why moving the screen closer to the object made the shadow smaller) was an especially striking reminder that conceptual change took time and involved giving up strong intuitive beliefs.

For the second and third weeks, teachers taught small groups of children, ages five to eight, in a morning summer camp. Two teachers were responsible for each small group; one taught the group and the other coached, with roles reversing for the second week. Although the small groups were unrealistic in terms of their usual teaching loads, we wanted to follow Case's (1978) instructional design and reduce the cognitive load on teachers while they were learning new content and new strategies. During each teacher's week of teaching, one lesson was videotaped; in the afternoons, that teacher and her coach met with us to discuss the tape (other teachers were welcome, but not required to attend). Afternoons were spent exploring new light and shadows activities, discussing issues of children's understanding in lessons, and constructing materials and activities for the next lessons. Each teacher kept a log in which she reflected on teaching, learning, feelings about lessons, etc.

In the last week of the summer program, teachers interviewed children again to assess their progress, and then met in grade-level teams to discuss activities and plan a two-week unit for their own classes in 1986-87. This week turned out to be a considerable frustration to all, because many were inexperienced at writing curriculum, and had great difficulty transforming their new knowledge of content, children and activities into a workable unit.

In October of 1986, each teacher was interviewed about her content knowledge again, in a clinical interview with questions parallel to, but not identical to, the June interview. Throughout the 1986-87 school year, teachers met once a month to continue discussions of physics content, teaching strategies, children's thinking and management issues.

Data Analysis

Audiotapes of teachers' content interviews were transcribed. Two raters independently scored each interview, with 87% agreement. The results are summarized in Tables 1 and 2. Teachers' logs were transcribed and excerpts relating to the teacher's subject matter knowledge selected. Videotapes of each teacher's summer camp lesson were transcribed and events in which subject matter knowledge was critical were identified. Similarly, audiotapes of teachers' stimulated recall interviews were transcribed and teachers' comments relating to subject matter knowledge identified.

Results

Teachers' June substantive content knowledge

In the first content interview about light and shadows, teachers' knowledge was fragmented and often provided evidence of conceptual flaws similar to children's misconceptions. Table 1 provides a summary of their answers. Teachers groped for memories of terms like *reflection* and *refraction.* They could sometimes remember the words *waves, rays* or *particles,* but these appeared to be isolated fragments in memory. One would ask "Isn't it rays?" but then fail to use the idea in later explanations. Answers were often based on episodic knowledge (e.g., "I know I've done that, so the shadow gets bigger"). At best, their knowledge was procedural in nature; they could tell what to do but when pressed for an explanation, admitted they did not know. The exception was an experienced upper grades teacher (Ms. White)

who correctly answered all except one of the interview questions and referred to a conceptual model (rays travelling, bending, refracting) throughout her explanations.

Most teachers referred to light as something that "lights up" an area or gave examples (e.g., the sun or electricity), much as children do (DeVries n.d.; Anderson and Smith 1983b). Although nearly all knew that a shadow resulted when light was blocked in some way, one called it a reflection and another a projection. However, their general lack of a conceptual model of light travelling in all directions from a source led to faulty predictions about the size of shadows. Most were procedurally correct in describing how to make a hand shadow bigger or smaller; however, half then predicted that, in order for the shadow to be the same size as the hand, the hand should be half way between the light and surface (see Figure 1).

The lack of a model of light actively travelling in a direction also led to predictions that a dog sitting within the shadow of a house would have a shadow (or maybe a faint one), because light was available around the dog. The active role of light in vision was similarly not well understood; only one referred to the reflection of light from the dog to the boy's eyes as the reason why the dog could be seen, when the house was blocking the light. Others fell back on assertions ("I know you can see him") or mentioned the available light as necessary to "look through" in order to see the dog. This latter notion of light as static substance which brightens, and of the eyes playing the active role in reaching out and "grabbing" images, is common among children, as well (Anderson and Smith 1983b).

When asked for explanations of phenomena which required conceptual knowledge of the wave properties of light, (e.g., what would happen to light falling on a prism), teachers answered that it would reflect off, go through unchanged, be bent but emerge as white light, etc.; even those who knew that the spectrum would appear could not explain why or how that happened. Explanations for the red color of an apple also sometimes resembled those which children give; one suggested that the color was part of the apple and "light had nothing to do with it." While others could mention words like spectrum or tried to recall "Isn't white the absence of all colors?", only three correctly explained the relationship of absorption and reflection of wavelengths to the eye.

Influences of content knowledge on teaching

Teachers' difficulties with the physics content had effects in several ways: on their confidence, ability to interview children, focus of activities with children, and use of examples while teaching.

In their June interviews, all but two teachers discussed at some length their lack of science background and feelings of inadequacy in science content. Ms. Clark summed up the feelings of many others:

> You know, kids enjoy it [science] but I think they [teachers] shy away from teaching it, and I think my own lack of, not knowing what to do is the reason I am not doing it... Science always has sort of a special feel when you hear the word -- "Oh, that's for smart people," and you are an elementary major and you will stick with reading and math and that kind of thing.

Teachers admitted that they avoided teaching science, and physics in particular, because of their own lack of knowledge. In fact, Ms. Duke revealed that she had wanted to quit, upon hearing that we were to do physics in the summer program.

> I was thinking I would love to do something about the beach and seashore. I had no idea. And she [another teacher] said, "I heard it's physical science." Well, you have ruined my day. I hate you; why did you say that? I don't know, I guess...well, I guess magnets would be physical science. I never had physics.

Over the four week summer institute, teachers struggled with their fears about content as well as the content itself. While they enjoyed the physics activities (e.g., covering an entire wall of the classroom with paper in order to make the biggest thumb shadow), their comments and logs revealed many difficulties. Ms. Stein wrote about making the huge hand shadows:

> Seemed very complex to grasp and takes time to sort out each situation. It is necessary to become actively involved in order to understand concept of light and shadow.

In another activity, Ms. White and Ms. Evans were trying to make double shadows, using just one light and one object, with the aid of a mirror. The first author and Ms. White were trying to figure out why the "reflected" shadow appeared where it did; when Ms. White used the terms "angles of incidence and reflection," Ms. Evans exclaimed in dismay and panic, "Oh, I knew it was going to get like this!" For her, still struggling with constructing an initial model of light as travelling, such terminology was a reminder of too many science courses in which content was covered too fast, understanding fell by the wayside, and memorization sufficed (see Anderson 1987, for examples).

Teachers did come to realize some of the power of a conceptual model and the thrill from understanding physical phenomena. Ms. Lake commented in her log, after an afternoon making mirror mazes--

> Reflected light is collected and reflected by each successive mirror. I loved the afternoon of discovery.

And later wrote --

> One big help is knowing that the light travels in straight lines -- the principle is the same with cameras and the reflection in the mirror. The logical approach to solving the problems that we have encountered makes it seem easier. The talking through the "why" of things is helpful, too.

While working as a group on a lesson about mirrors and reflection, Ms. Duke (whose aversion to physics was quoted earlier) exclaimed

> This is so fascinating! I can see why people become physicists.

And in her log wrote

> Later after lunch, we came back to play with mirrors. It was fun, yet mind boggling. I'm still pondering how we see, let alone this new information! I guess I could be here all summer.

For teachers who began with naive conceptions of the nature of light, one week's activities were obviously not enough. By the end of the first week, teachers were interviewing children and planning for the summer camp. Ms. Evans later commented about the interviewing in this way:

> Yeah, that was confusing to me even when we tested the kids...we had the one doll in front of the other, and I was asking those questions like crazy and I was going, "Oh (expletive deleted), I really don't know this." You know, really, especially when we do the pre-interviews, we had done that stuff but it just really hadn't, you see it still hasn't all, it takes a while.

Despite teachers' struggles with the physics content, in their summer lessons, they were accurate and made few errors. For the most part, this was because many stuck closely to the kinds of activities they themselves had done in the first week, or modified them slightly. These activities were familiar, teachers knew what to expect, and had a sufficient level of procedural success to insure safety. However, the focus in most of these lessons was on children's procedural knowledge - e.g., how to move the shadow, how to make it bigger - with few links to conceptual understanding which might have provided reasons for successful procedures. For example, Ms. Stein began her pre-lesson interview, "we're going to focus on changing shapes of shadows by moving the objects in as many different positions as possible." And when asked what the goal for children was, she responded, "...to get the children to understand that you can change the shape of the shadow by moving the object in as many different ways". In the lesson, children successfully made shadows larger and smaller by moving the object closer to or farther from the light, but were never asked to explain how or why their procedures were related to the light. Next, they tried several ways of turning the doll to make different shaped shadows, again successfully and again without reference to the role of the light. In the following exchange, the focus is on what to do, not why:

> Stein: Did we change the shape of the shadow, Jane?
> Jane: Yes.
> Stein: Yes we did! How did we change that shape? Jane?
> Jane: Um, we turned it around to make it thinner.
> Stein: We turned it around to make it thinner. So we did change the shape of that shadow. By just turning it around. Susan, do you think you can change the shape of that shadow one more time? (Susan

> shakes her head no.) No? Why not?
> (long wait time). Would you like to
> try it? Try moving it around.
> (Susan shakes her head no again.)
> Harry: I can, I can move it a little
> bit both ways.
> Stein: A little bit of both ways.
> All right come up and show us then.
> Harry moves the doll a little.) What
> did you do to it?
> Harry: I just ...(adjusts the dolls
> again).
> Stein: You just...what did you do?
> Harry: I turned it a different way.
> Stein: You turned it a different
> way. But it was just a little bit.
> And it's another different shadow.
> Rick, can you change it one more
> time? (Rick turns the doll.)
> Another way to change that shadow!
> Bruce, can you change it one more
> time? (Bruce turns the doll in the
> opposite direction.

This kind of procedural focus, even when combined with occasional requests for predictions, omitted the need for children to dig deeper and consider the active role of light in the shapes and sizes of shadows.

Underneath the apparently calm surface of lessons, for some teachers, uncertainties about their own content knowledge were revealed in logs and stimulated recall interviews. When Ms. Evans was asked, in her pre-lesson interview, if she expected any problems, she commented, "...if I don't mix up the model of the light and the size of the shadow myself. I still feel uncomfortable about that." During the lesson, in fact, she reviewed children's work on size by having them demonstrate and describe what happened, without referring to the model of light at all. And when Annie incorrectly predicted a longer shadow with the light overhead, and gasped to see a much shorter one with the light on, Ms. Evans hesitated, then went on with the next part of the lesson. Her own problems with the content may have contributed to this decision, because in her stimulated recall interview, she wasn't sure what had happened - "when you raise it (the light) up higher, it really doesn't make any difference (in the shadow)...in fact, I think it started to make the shadow small."

What was missing from many of these lessons was a focus on the conceptual understanding of light and the use of examples, metaphors, analogies and multiple representations that might have allowed children to construct relationships and mental models.

The one exception, again, was Ms. White. Her excellent conceptual knowledge appeared to allow her to generate new activities, new representations to assist children's understanding, and more use of examples and applications to everyday events. For example, she constructed a "spaghetti model" of light (strands of spaghetti stuck into a styrofoam ball), and used it in most of her lessons, for children to predict what would happen in activities. She assisted their cognitive movement back and forth between the model and concrete materials and events. In her videotaped lesson, she asked children to consider the limitations of the model by pointing out that some materials (e.g., a hair) would pass in between the spaghetti and asking children whether that meant some items would be too thin to make a shadow. This kind of familiarity and flexibility with the content, in order to construct activities, examples, and explanations to facilitate children's understanding is what teachers whose own content knowledge was under construction seemed to lack.

Unfortunately, this very willingness to generate metaphors and examples also led to some misleading uses of the model, too. For example, when using the spaghetti model to talk about light in a tube with a bend, Ms. White suggested that the tube "forced" the light down the tube, as if the light could be bent by the walls of the tube (instead of absorbed and/or reflected). Although Ms. White and the group had earlier discussed how light was stopped when it reached objects, in this case, that knowledge was not applied to the paper tube. So, while Ms. White's conceptual knowledge usually paid off in confidence and the use of examples in lessons, occasionally it went awry, with the possibility that children were misled or confused.

Teachers' October substantive content knowledge

Results of teachers' fall physics content interviews are summarized in Table 2. Teachers had made substantial progress in conceptualizing a mental model of light, and in understanding shadow phenomena. For example, in their June interviews many were limited to episodic knowledge of light - e.g. giving examples like "the sun, the moon"; in October they responded with properties of light (which had been noticeably absent in June) - e.g., "travels in straight lines, can be bent, can be reflected". All explicitly stated that shadows resulted when light was blocked in some way from reaching an area. Half knew immediately that two lights shining on a child seated between them on the floor (see Figure 2) would result in two shadows; four of the five who predicted only one shadow had misinterpreted the drawing and when they realized that light from both lamps was hitting the girl, drew in the second shadow.

Throughout this fall interview, teachers were more active in drawing the light rays diverging from a source in straight lines, and in verbalizing their thinking about problems. While their drawings were sometimes incomplete, when prompted they finished the drawing, realized the implications and accurately explained the problem. For example, when predicting the size of a shadow of a block, six immediately drew the rays and sketched out the area of the shadow, showing it as larger than the block. The others had initially drawn the shadow approximately equal in size, but after drawing in rays from the source, quickly corrected the size.

Four teachers explicitly mentioned Ms. White's spaghetti model during the interview and many prompted themselves with comments like, "well, we know light travels in straight lines." Even those who were initially inaccurate or unsure, when prompted to use the conceptual knowledge they had, went on to solve problems accurately, usually to their own amazement. For example, when asked to explain how shadows were involved in a solar eclipse, Ms. Clark first said, "Is that something to do with the way the earth and the sun are lined up? But...I really don't know." However, when prompted to think about what we see in an eclipse, she quickly realized that something had to be blocking the sun's light, and that object was the moon. She then drew the sun, moon and earth correctly and said, "So, then this would be the earth, this would be the moon, and this would be the sun all lined up together, is that how that goes? Okay." When I responded, "See...you knew that," she replied, "I didn't think that was anyplace in me to grab." Several other teachers solved problems which they initially had denied knowing how to do, in the same way. When they stopped and considered how what they knew might be used, they were able to work their way through and provide explanations for their answers.

An interesting exception to the overall accuracy and confidence with which most teachers answered questions about shadow phenomena was the Mikey-David problem on merges (see Figure 3). We had actually done this with two children in the summer camp, and teachers had all watched the smaller child's shadow "swallow up" the taller one's. Yet, several insisted that the shadow on the wall was the taller child's, even when their own drawings showed the sizes of the shadows (this problem became an important one in the monthly seminars, as we shall see). Three of these teachers corrected themselves, after drawing the rays and shadows, but seemed unconvinced. Ms. Evans commented, "All I remember is this little sucker standing up here and thinking, 'I should...' I didn't quite get that."

With problems which had received less time and attention in the summer, teachers were less accurate and less confident. Even here, however, more teachers showed an understanding of the principles involved than they had in June. For example, in understanding the role of light in vision, eight of the ten immediately drew rays from the sun to the object and then to a person's eyes; in June, only one had accurately explained how we could see a dog sitting in a shadow.

A slightly harder problem, about the role of light in seeing a mirror image, instantly elicited groans of dismay from several of the teachers. Four talked about their memories of the drawing we did on the chalkboard in one of the teachers' summer lessons; for example, Ms. Stein said, "Well, I can remember that drawing we did on the wall...I'm trying to imagine that picture on the board, and I can't think". They could remember its form but not its meaning, and eventually drew the light as emerging from the eye to the mirror or shoe. However, five teachers accurately traced the path from the shoe to the mirror and from there to the eye, and made sure the angles were equal.

Problems on refraction, absorption and reflection, which we had not studied during the summer, were the hardest. For these problems, teachers fell back on their own episodic knowledge, (as they had in June) and tried to relate any experiences they had had, in generating an answer. Ms. Duke, for example, tried to recall what her red night light did to the blue bathroom tile,and then used that memory to guide her reasoning about green light on a red pot.

Teachers' substantive knowledge content knowledge had changed, often dramatically, over the summer. Ms. Evans' comments in her fall interview provide the clearest example of change and her feelings about her growth in content knowledge. In answer to the question, "What is light?", she responded --

> E: It's the absence of darkness, I know that much, and it's energy and it travels, and moves, and bends, and is all around except when it's dark, and you break it up into the different colors of the spectrum, and it could be a force, like a laser. If you concentrate it, it spreads.
> D: You know a lot.
> E: More than I knew when I came in the summer time.

And later in the interview, she commented --

> E: I just love it because I know so much.
> D: I know. Doesn't it feel great?
> E: Must be how kids feel...

Subject matter content knowledge represented both barriers and triumphs for the teachers with whom we are working. Their reflections on their difficulties and embarrassments in their own learning, and appreciation of the struggles required to change old concepts and construct new ones were important information for them. Although we had read Gruber's (1974) "Courage and cognitive growth in scientists and children," it was their own moments of hesitation and courage in group discussions of content and their own triumphs in figuring out problems which were the most powerful examples for them.

Discussion

There are several issues which have emerged from this work with primary teachers which deserve some discussion. I'd like to consider, first, the novice state of their physics knowledge and its similarities to children's knowledge; next, the process of conceptual change in their thinking about light and shadows; and finally, the influence of their content knowledge in teaching, and implications for further work.

In their June interviews (with the exception of Ms. White), the primary teachers revealed an intriguing array of knowledge about the physics content. Everything from isolated bits of declarative knowledge, to procedural success, to episodic memories for particular events, common misconceptions, and pieces of a conceptual model showed up.

What is most striking to me is the similarity of much of their knowledge to that which children have. This is not to label these teachers child-like or immature. What I want to emphasize is the danger in assuming that adults, by virtue of their maturity, will have an easier time with physics concepts than do children. Unlike Shulman and his colleagues' work (e.g. Wilson & Shulman 1987) on beginning secondary teachers who have majored in the domain they are to teach, our teachers were novice learners in the domain, although fairly experienced as teachers. We have some evidence that adult novices in a domain hold misconceptions and solve problems in ways similar to younger students (e.g. Apelman 1984; McCloskey 1983, Clement 1983; diSessa 1982). Our work with these teachers suggests that the starting points in coursework in science content and in inservice work may need to be carefully re-thought. Anderson's (1987) work with preservice teachers in a science content course points out that conceptual understanding, from the college instructor's point of view, may not be the goal. Unless we provide beginning elementary teachers with the kind of coursework which allows them to understand at least some of the science content they are to teach, and then provide staff development and/or curriculum materials with a focus on the teacher's own understanding, it is unlikely that teachers will be able to tutor themselves through the bewildering number of science concepts in the elementary school curriculum.

Secondly, the process of conceptual change for these ten teachers looked very similar to that which children undertake. It took time, much more than I had anticipated. It required the opportunity for redundancy, review, and reconsidering what we had done. Teachers who had alternate conceptions (e.g., of vision) had a difficult time giving them up, and used their memories of activities and discussions to support their prior conceptions. For example, several teachers whose own models of vision included an active eye looking through the light to an object, maintained this model in the October interview. If conceptual change for children takes time, redundancy, and contradiction of preconceptions (e.g. Resnick 1983), it appears that conceptual change for adult novices who are teachers does, too (e.g., Apelman 1984).

Teachers' procedural successes preceded their conceptual understanding, just as children's success often precedes their understanding, (Piaget, 1978). Even those who were correct in their ability to predict the correct action for making a shadow larger, and to draw the size/distance relationship between an object and its shadow, sometimes failed to make the connection to the conceptual model. In our monthly seminars, the Mikey-David problem continued to be a source of frustration. At one meeting this spring, it was assigned as the homework/boardwork. There was vociferous discussion, argument, drawing on the board and debate. Finally, Ms. Lake got out a light, pulled down the shades and positioned the tallest and shortest teachers in front of the light. When she turned on the light, several gasps and excited exclamations broke out. "I got it! I got it! It's because she's blocking more of the light - she's closer!" - this from Ms. Evans who had successfully answered all the size/distance problems in October (although the Mikey-David problem had given her some difficulty). Getting it and understanding it, in a way that solidifies conceptual knowledge and enables a learner to apply concepts and use them for problem solving, are often two entirely different things for children (Gilbert and Osborne, 1980) and for teachers.

The process of conceptual change for teachers also revealed the power of representation, especially mental imagery --- both to support and to hinder understanding. Many teachers referred to and used, either explicitly or implicitly, the spaghetti model which Ms. White had made - especially when they were unsure and needed to figure something out. On the other hand, the mental image retained from the summer board drawing about mirrors appeared to hinder those who had not understood its conceptual meaning at the time. Those whose understanding of vision and/or reflection was shaky and unsure could not use their memory of the drawing to generate a solution; their October drawings showed lines drawn almost exactly as in the summer diagram but with light rays from the eye to the mirror or from the source to the mirror, just as they had described in June.

Finally, in the process of giving up old ideas about light and shadows, and constructing new ones, for seven of the teachers feelings of necessity emerged; even when they were unsure that they were accurate, they expressed feelings that if their understanding were true, then the representation and the result had to be.

Here is Ms. Evans, discussing whether candlelight reaches a person's eye in the daytime:

> "It's gotta still be there because...it's gotta be. Where else could it be? It has to still be coming out because it's not dark. So if it's daytime, you can see that. Is that true?"

And again, it was Ms. White whose interview was full of expressions of necessity about her solutions. In the case of reflected sunlight off a hatchback blinding a driver behind the car, she worked backwards in this way:

> "Well, let's see, if it's in your eye, and it's gotta be coming in like this off of the glass...is going to be like that I guess (drawing equal angles to and from the glass). So it's got to be morning time, I guess, 'cause the sun is coming up."

These expressions of necessity are interesting for three reasons. First, Piaget's (1983) most recent work focused on children's appreciation of the necessity entailed by their theories and explanations about phenomena; in that work, he argued that the understanding of what is necessarily true was the sign of deeper, principled conceptual understanding. Second, the research on expert/novice differences in understanding and problem solving in a domain (e.g. Chi, Glaser & Rees 1982) also reveals important differences in appreciation of principled constraints within a domain. Finally, recent work in the history and philosophy of science (e.g. Lakatos,1978) has also emphasized the role of core constraints in theory change.

The emergence of teachers' feelings of necessity, which was not taught or discussed during the summer, provides some evidence for the qualitatively different conceptual knowledge which was under construction and increasingly available for reasoning about physical phenomena. This was an unexpected and interesting aspect to their knowledge, and one which hints at the power that a conceptual model affords. It is exactly the unanticipated events in classrooms - which do not have immediate, apparent solutions - which are the source of worry and embarrassment for primary teachers. If their conceptual knowledge provides them with a way to think through (ideally, aloud so students can observe the process) such situations, and to discuss what might be true if the model is correct, then much of the anxiety in science lessons might be reduced. It is not entirely clear yet, from this data, what such knowledge might buy teachers in classroom lessons, and remains to be studied in teachers' later classroom work.

So, what difference does teachers' content knowledge make in their teaching? It is already clear, from our data and that of others, that the decision to teach science is affected by teachers' confidence about the content. What teachers are willing to try is what they feel has a reasonable chance of success, for themselves and the children they teach. Beyond that, it is likely that the amount of time allocated for science depends to some extent on confidence and enjoyment of the content (Schmidt and Buchmann, 1983). And within the time allotted, as our summer lessons demonstrated, the relative amounts of time set aside for procedural activities, discussion or diagnosis, may be influenced by the teacher's own level of understanding. Teachers' own procedural success appears to beget a focus on procedural success in their lessons. Conceptual understanding, at least with our teachers, appears to lead to more of a focus on the conceptual model, its predictions and problems.

Most importantly, from our work with these teachers, it appears that mastering a new subject domain and trying to teach it may produce a kind of U-shaped curve (e.g. Strauss, 1982) in teaching performance (especially when combined with mastery of new teaching strategies and of new knowledge about children). It may be that a longer period of time spent only on content, with time for more consolidation of conceptual understanding, would have resulted in more initial success for teachers in their lessons, and more use of appropriate examples and metaphors. Yet, it was exactly the kind of grappling with ways to teach children and have them understand, that teachers found sometimes helped their own understanding. One of the teachers explained why she couldn't remember how shadows were reflected in a mirror in this way -

> ...I played with mirrors, I didn't plan with the mirrors, that was the whole big difference. You got all excited and you did this, and then moved on to something else and didn't bother to figure out what you really saw, where (White) and (Evans) had to think about what they saw (because they were planning lessons on mirrors).

Gunstone and Northfield (1986) report that teacher trainees with whom they worked were motivated to master content because they would be teaching that content in six weeks. For the primary teachers in our program, who were getting ready to teach in the next two weeks, understanding in order to teach was similarly an important motivation.

Certainly, the exploration of alternatives in the timing of teachers' content mastery and its translation into content for teaching deserves more study. In the meantime, supervisors, principals and curriculum developers should be aware that teachers' initial attempts may look worse, not better. Inservice programs, staff development plans, and curriculum guides will need to allow for the time and support necessary for teachers to master the content, translate it into teaching and integrate the new lessons into their current repertoire.

CONCLUSIONS

The current research on teachers' content knowledge, and our work with these ten primary teachers, are attempts to "find" what Shulman (1986) called the "missing paradigm." Yes, teachers' knowledge of the content and the ways in which they have it structured - especially in science domains where they are likely to be novices - is important for understanding their teaching. It is important, not just because we'd like the factual content of lessons to be accurate, but also because of its influences on confidence, allotment of time, the focus and goals of lessons, and on the ability to generate explanations and solutions in uncertain classroom events. Ms. Clark, in her October interview, articulated her understanding of the role of her own content knowledge.

> "But...I think just as a facilitator really, you have to know what happens if you do that, when they think they have no answer. But that puts a lot of burden, I mean you really

> have to know your subject matter strongly to know the questions to ask. You know this kind of thing, which is something that makes it scarey for me to put it into a situation like this, because I don't know if I will know enough of it - the right questions that keep leading them further."

In addition, information about teachers' content understanding is important because they *are* likely to be novices in various science domains; as such, they will need to construct new concepts, procedures and mental models, and to change former ones, just as children and other novices do. We will need to provide opportunities, motivation and support for them to do so, so that they can feel the excitement of more adequate explanations and the generative power of conceptual models in their own teaching.

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TABLE 1

TEACHERS' SUBSTANTIVE CONTENT KNOWLEDGE (June, 1986)
(for 8 teachers)

light is	energy 3	allows to see brightens 4	gave examples 6	opposite of dark 2	waves, rays particles 6 *	
shadow is	blocked light 7		reflection 1			
light shining on glass will be	bent 2	reflected 6	go through 8			
light shining on wood will	be reflected 2	light up wood 8				
light shining on mirror is	reflected 7	mentions equal angles 2				
light through prism	straight through 2	bent only 3	mentions colors 4	no colors 2	reflects 3	bent and colors 2
to make shadow bigger	correct (hand & light closer hand & wall further) 6		incorrect (hand to wall) 2			
to make shadow same size as hand	close to wall 4		half-way between wall and light 4			

*numbers do not total 8 because some teachers gave more than one answer

to make shadow smaller than hand	can do but don't know how 2	not sure 3	not possible 1	hand to wall or away 2	
to change location of shadow	just move hand (light reaching ceiling) 1		direct light to ceiling 7		
how do we see red apple	don't know/ forgot 2	colors part of apple 1	mentions spectrum absence of colors or eye 2	all others absorbed red reflected 3	
merged shadow of dog in house shadow	would be there 3		no shadow 5		
can see dog in shadow?	don't know 1	still light to illuminate 4	light to look through 1	other light reflected to eye 1	
why pencil in water bent?	density causes light to bend 2		water does something 4	reflection 1	other 1

Table 2
Teachers' Substantive Content Knowledge
(for 10 teachers)
October, 1986

what is light	energy 5	travels in straight lines 4	can be bent 3	reflects 2	gives examples 3	reference to model 4	beams, rays 6	has all colors (1) opposite	1 correct
what is shadow	light blocked 10	absence of light 5							
role in vision (candlelight)	light travels to eye 6	illuminates 0	reflects off flame 1	only relative to sun/moon brightness 4					
role in vision (tree)	bounces off tree to eye 8	illuminates so can see 2	eye to tree 0	not sure 2	wavelengths absorbed and reflected 2				
two lights, double shadows	2 shadows 5	one shadow in front 1	changes mind 4						
role in mirror image	light bounces: source-shoe-mirror-eyes 5	equal angles 5	eye to mirror or shoe 4	mentions drawing/ lesson 4	not sure 1				

*Nunbers do not always add to 10 because some teachers gave more than one answer.

solar eclipse	correct sun-moon-earth 5	not sure 4	confused with lunar 1	figures out with prompt 5	shadow of earth 1	
refraction - penny in water	light bends in water 6	light from penny bent to eye 3	see image, not "real" penny 1	not sure 1	water magnifies 1	penny will float 1
size/distance of block shadow	shadow > block 6	shadow = block 4	draws rays as channel 4	draws rays diverging 6	corrects after drawing 4	
light reflected on car window	equal angles 3	unequal angles 6	refers to own experience 2			
cloudy day shadow	not enough light 5		light diffuse 2	refers to own experience 2	shadow there 4	
green light on plant	wavelengths absorbed and reflected to eye 2	don't know 5	confused with color mixing 1	confused about absorp/reflection 2	wrong - white and black 2	
angle of light/ length of shadow	AM long/PM small 8	incorrect 2				
merges	correct shadow/person 3		verbalizes distance/ size of shadow 0	incorrect shadow/ person 6	corrects self 3	
rainbow	correct sun-person-rain relationship 3		refers to light bent and refracted to eye 6	white light has all colors 0	not sure/DK 2	refers to own expers. 2

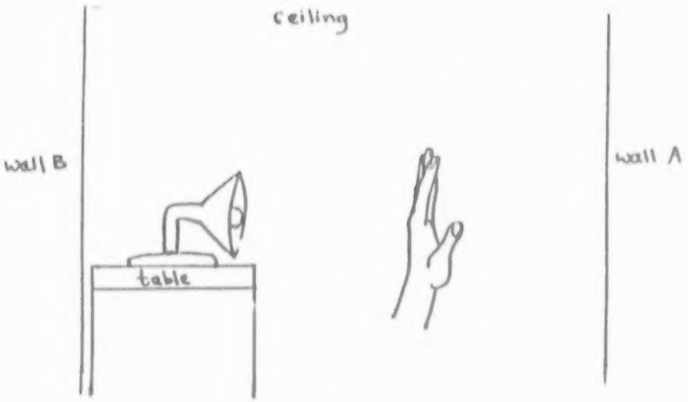
ceiling
wall B
wall A
table

Figure 1

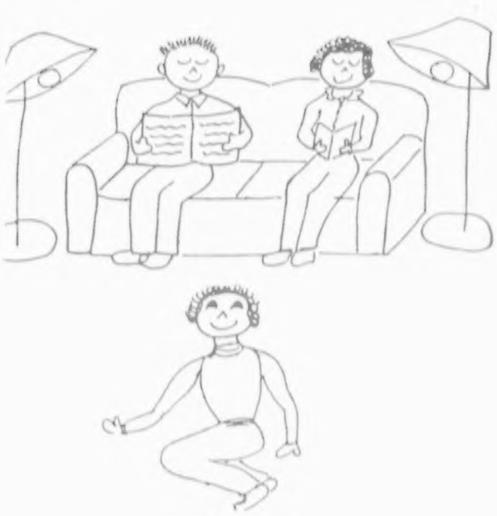

Figure 2

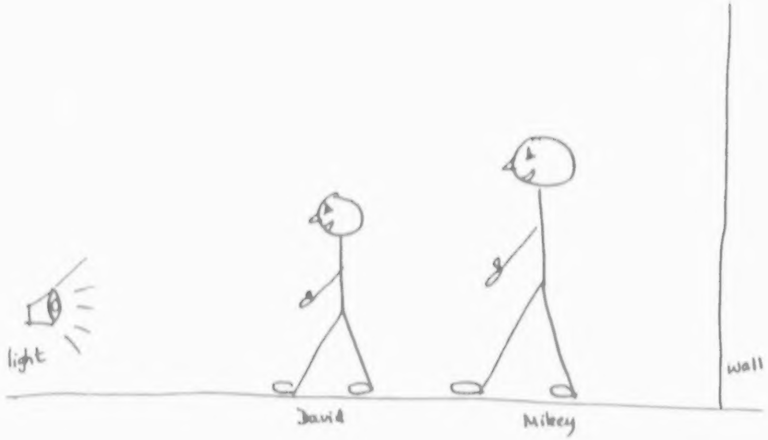
light
wall
David
Mikey

Figure 3

Computers as Tutors: MENDEL as an Example

by

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Introduction

In this paper we describe the progress that we have made on the development of MENDEL--an intelligent tutoring system in transmission genetics. Tutoring system research is a growing specialty within the fields of artificial intelligence and cognitive science (Anderson, Boyle, & Reiser, 1982; Sleeman & Brown, 1982; Steels & Campbell, 1984; Wolfe & McDonald, 1985; Schute, Glaser & Resnick, 1986; Clancey, 1987; Kearsley, 1987). It deals with efforts to model: the phenomena of a content domain; the problem-solving performance of discipline experts and learners; the tutoring behavior of humans; and the communication interface between humans and computers. The goal of this research is to create computer software capable of providing students with advice that is appropriate to their level of knowledge, their level of problem-solving performance, and their domain understanding.

The primary objective of the MENDEL project is to provide a computer environment for transmission genetics in which students can develop model-based problem solving by conducting realistic genetics experiments and receiving appropriate problem-solving advice (Stewart, 1987a). The larger goal is to demonstrate that: students can design problem-solving experiments for realistic genetics problems; computer programs can contain model-based problem-solving strategies of expert geneticists as well as the advising and tutoring strategies of successful genetics teachers; and students are capable of developing model-based problem solving when placed in such a simulation and tutoring environment.

In this paper we will describe the MENDEL software as well as the educational research related to its development. The software includes: a problem GENERATOR; a TUTOR that includes model-based tutoring strategies; a student MODELER that includes a model of student performance; an ADVISOR that questions students and provides them with tutorial advice; and an hypothesis CHECKER that evaluates students' hypotheses. See Figure 1 for a representation of the relationships among these software components.

Figure 1 Here

The research which has led to the development of this software includes studies of: expert and novice problem-solving performance; tutoring strategies of genetics teachers; student use of MENDEL's notational tools; and effective advising strategies to help novices understand model-based problem solving.

The MENDEL Software

The Problem GENERATOR

The problem GENERATOR contains a model that simulates significant transmission genetics phenomena. It includes a problem customization section, a problem-solving environment, and an hypothesis-entry facility. The customization section and problem-solving environment are an elaboration of Jungck and Calley's (1985; 1986) GENETICS CONSTRUCTION KIT program. More complete descriptions of the GENERATOR can be found in Streibel, Stewart, Koedinger, Collins, and Jungck (1987) and Maclin, Allman, Streibel, and Stewart (1987).

The Customization Section

Using this section, an instructor can create a class of organisms with certain trait names and variation names for each trait, and genetic parameters for that class of organisms. The genetics parameters consist of the number of traits (1-4); the number of variations for each trait (1-10); the range of progeny (1-99) for any cross; the inheritance patterns (simple dominance, codominance, multiple alleles, and gene interaction); and modifiers of these inheritance patterns (lethality, penetrance, pleiotropy, sex linkage, and autosomal linkage). A template from the customization section that was used to create a class of problems is shown in Figure 2.

Figure 2 Here

The Problem Solving Environment

Students use the problem-solving environment without knowledge of the specific customization parameters. They are presented with a phenotypic description of an initial population of organisms (generated randomly within the constraints of the customization parameters) and can then produce as many offspring generations as desired by using the cross option. They continue to make crosses and perform statistical tests on the cross results until they are satisfied that they can explain their data in terms of inheritance patterns and modifiers. Thus, decisions such as whether enough data has been collected, or what the results of statistical tests mean, must be made by students as they develop genetics-specific problem-solving strategies as well as more general scientific inquiry skills. A significant feature of this software is that it allows students to assume the responsibility for posing their own problems and for designing and interpreting their own experiments. Figure 3 is an example of an initial population shown in an abbreviated (vial A) and expanded form (invoked by the List option).

Figure 3 Here

Even though the GENERATOR does not completely simulate all of the activities of a transmission geneticist (e.g., the student does not have to raise organisms, divide their characteristics into discrete analyzable traits and variations, or analyze environmental effects on phenotype), it does provide for a richer problem-solving experiences than those typically experienced by high school or undergraduate biology students.

The Hypothesis-entry Facility

The Hypothesis-entry facility of the GENERATOR includes several notational systems that permit students to observe and manipulate multiple representations of their data and genetics objects. The facility was developed to allow students to enter inheritance pattern and modifier hypotheses for the traits being considered and to become more proficient at model-based problem solving. The facility includes the following components:

1. Hypothesis-Entry Mode, to permit students to enter their hypotheses;
2. Current Hypothesis Summary Form, to serve as a data-management summary of the students' hypotheses;
3. Chromosome-Pair Graphs, to summarize students' hypotheses about inheritance patterns and modifiers at the chromosomal level;
4. Expression Charts, to display the complete genotype-to-phenotype relationships for any inheritance pattern and modifiers for any trait;
5. Expression Graphs, a more generalized form of expression charts;
6. Pedigree Diagrams, to enter cross-generational hypotheses about class genotypes and to display offspring across generations.
7. Punnett Squares, to display aspects of genotype-to-phenotype relationships based upon Mendel's principles of segregation and independent assortment;
8. Cross Patterns, to represent cross possibilities for each inheritance pattern;
9. Inquiry Strategy Tree, to display the overall inquiry strategy that the SOLVER uses to solve the same genetics problem as the student.

Sample hypothesis-entry screens are shown in Figure 4. This facility was added to the GENERATOR because we have found that students often did not: generate hypotheses; relate genotypes to phenotypes; think in generational terms; relate their problem solving to the events of meiosis; or consider multiple explanations for their cross data (Stewart, 1987; Albright, 1987; Slack, 1987). Hence, the hypothesis-entry facility was designed to encourage students to generate population-level and cross-specific hypotheses; the expression charts and graphs were designed to reify genotype mappings and make these mappings cognitively accessible as well as manipulable for the students; the chromosome-pair graph was designed to display a visual representation of the relationship between chromosomes, loci, traits, and variations; and finally, the hypothesis summary form was designed to keep track of student hypotheses about the genetics of the data before them.

Figure 4 Here

The following descriptions of the pedigree diagram and chromosome-pair graph notational systems illustrate how students are helped to think in model-based terms.

The Pedigree Diagram. The pedigree diagram helps students think in trans-generational terms by summarizing existing data across generations. As shown in Figure 5, the pedigree diagram allows students to enter possible genotypes for each parent organism and class of offspring (where there are ?? in the pedigree). Use of this option underscores the point that more than a single genotype-to-phenotype mapping is possible (e.g., crossing like phenotypic variations and getting the same variation in the offspring could be accounted for by three simple dominance cross patterns). By entering possible genotypes on the pedigree diagram, students are encouraged to see crossing as a procedure for producing knowledge about the population.

Figure 5 Here

The Chromosome-Pair Graph. The chromosome-pair graph, on the other hand, helps students see the interrelationship of genetics knowledge at the meiotic level. For example, if students enter an hypothesis that the first trait in a problem is due to simple dominance with sex-linkage, they see a graphic representation of this hypothesis on the chromosome graph. If they then hypothesize that the second trait is linked to the first one, they can see the consequences on the chromosome-pair graph. They can then test for this side effect by performing the appropriate crosses to confirm or disconfirming it. The chromosome-pair graph provides students with a pictorial representation of their current hypotheses at the chromosome level. Thus students are encouraged to relate meiosis and problem-solving, which is a basic aspect of model-based problem solving.

Our work on these notational systems has led us to three conclusions:

1. multiple notational systems help students grasp key aspects of problem solving in transmission genetics;
2. notational systems make expert forms of modelling genetics knowledge and problem-solving procedures cognitively accessible and easily manipulable for students; and finally,
3. notational systems can be used to model a student's understanding, including misconceptions, of the problem-solving task.

Although we originally designed the hypothesis-entry facility and notational systems to help the TUTOR gather data about student thinking during problem solving, we soon found that these notational systems served other functions as well:

1. communication links between the student and the TUTOR;
2. multiple windows to enable the students to see a graphic representation of the knowledge structures and reasoning processes of MENDEL; and
3. multiple ways of showing students the consequences of their hypotheses.

We are continuing our research on the role of the notational systems with high school, two-year college, and university students as they solve genetics problems using the hypothesis-entry facility in an attempt to determine the effect that these notational systems have on students' understanding of genetics problem solving.

The Problem SOLVER

The SOLVER contains a model of an expert that uses knowledge of genetics and genetics-specific heuristic problem-solving rules to account for the same data as confronts a student. The SOLVER does not have access to the genetics parameters that were defined in the customization section of the GENERATOR program. It is therefore an expert at making abductive inferences from phenotypic data (i.e., reasoning from effects to causes). The SOLVER is guided by a problem-solving inquiry tree that was derived from research on expert geneticists (Collins, 1987; Collins and Stewart, 1987). The Inquiry Strategy Tree is summarized in Figure 7.

Figure 7 Here

The goal of the SOLVER is to infer what inheritance patterns and modifiers are responsible for the phenotypic data that the student has generated. Each of the following steps in the inquiry tree works toward that end:

1. **Redescribe Initial Data** is the process of transcribing the physical data a student might see (such as trait names, variations associated with traits, and numbers of individuals) into a LISP frame that the SOLVER can manipulate.
2. **Experiment** is the core process of the SOLVER. The SOLVER repeatedly generates and tests hypotheses until it has narrowed the possible hypotheses to one. The hypotheses manipulated within this phase

of the inquiry strategy tree are within-trait hypotheses (i.e., independent of hypotheses of other traits).

- a. **Generate Hypotheses** defines a specific class of hypotheses that the SOLVER checks against the phenotypic data. A class is formed by deciding on an inheritance pattern and deciding whether sex linkage or lethality occur in the population. Each different combination of the four inheritance patterns (simple dominance, codominance, multiple alleles, and gene interaction), plus a different value for sex linkage and lethality, is tested as a specific hypothesis for a trait.
- b. **Plan Initial Crosses** examines the hypothesis and plans crosses to obtain new data.
- c. **Test and Refine Hypothesis** is the process of interpreting data from a cross and determining how well it fits each trait's current class of specific hypotheses.
    - i. **Pick Cross** examines the crosses that have been planned and picks one to be done. If the student asks for cross advice, the SOLVER suggests which cross to perform. Otherwise, the SOLVER uses the student's cross.
    - ii. **Redescribe Cross Data** is the process of transcribing data from the last cross into SOLVER frames.
    - iii. **Plan Future Crosses** chooses which individuals to cross to obtain new data.
    - iv. **Explain Cross** is a pattern-matching cycle that uses chi-square analyses. For each trait's class of specific hypotheses, an algorithm is applied to determine if a cross fits a specific hypothesis, and, if so, how well.
- d. **Check Alternate Hypotheses** examines the possibility that there exists an hypothesis other than the one generated that can also explain the data. Relevant information discovered here is made available to Generate Hypothesis and this section of the inquiry tree is executed again.

4. **Check Results** checks for across-trait modifiers and then reviews the solution.
    - a. **Check For Modifiers** checks for cross-trait modifiers such as linkage and pleiotropy.
        - i. **Plan Needed Modifier Crosses** plans the crosses that are needed in order to test for across-trait modifiers.
        - ii. **Pick Modifier Cross** picks a cross that was planned to test for across-trait modifiers.
        - iii. **Evaluate Modifiers** examines the data to see if a test for across-trait modifiers can be made. If the needed data exists then the test is made.
    - b. **Review Solution** checks to make sure that the solution is consistent with the available data.

As mentioned earlier, the SOLVER uses a heuristic search approach to generate hypotheses about inheritance patterns (that is, it considers the simplest and most likely hypothesis first) and to recommend crosses within the constraints of these hypotheses. For example, the SOLVER also contains hypothesis-generating rules (HGR) which are searched using the data from the redescription as the conditions. When a match is found between the conditions and an HGR rule, that rule is executed and the next step in the Inquiry Strategy Tree is begun. An example of an HGR rule is:

HGR 1 IF: (1) Goal: generate an inheritance pattern hypothesis (2) There are 2 variations for a trait

THEN: assume simple dominance is the inheritance pattern.

The SOLVER will then work with a simple dominance hypothesis until it has a justifiable solution to the problem or until there is data that logically contradicts the possibility of that solution. The SOLVER therefore also contains the logic of disconfirmation as well as the logic of abduction. By entertaining an hypothesis of simple dominance, the SOLVER has both reduced the search space of underlying mechanisms that might account for the phenotypic data and made a best first guess at such a mechanism. The SOLVER now has a way to match the phenotypic data against genotypic possibilities. It should be pointed out that the HGR rules have a considerable amount of genetics knowledge and problem-solving expertise "compiled" into them. The rules can therefore not be revealed to students directly in a tutorial manner without much additional explanation.

Once additional data is available the inquiry strategy tree directs the SOLVER to begin to test and refine its hypotheses. Before new data can be used, it must be redescribed with all appropriate frames updated and new ones constructed as necessary. The inquiry strategy tree then directs the SOLVER to explain the cross by making inferences about the new data. Again this is accomplished by the firing of rules, in this case cross explanation rules (CER). The exact rule that fires will be a function of the conditions that exist in the SOLVER's frames. The frames contain an amalgam of redescribed data and tentative hypotheses An example of one such rule is:

CER6 IF: (1) goal: explain a cross within a trait
(2) assumed inheritance pattern is simple dominance
(3) parents are of different variations
(4) offspring are of both variations
THEN: (1) one parent and the offspring with the same variation are homozygous recessive.

The design of the TUTOR was influenced by a philosophy of tutoring and by our research on the tutoring behavior of experienced genetics instructors. The empirical research is in its early stages and is only now being translated into specific tutoring strategies within MENDEL. The philosophy of tutoring, however, builds on the concept of post-Socratic tutoring (Jungck & Calley, 1985; 1986). Post-Socratic tutoring provides a framework for the interactions between the computer tutor and the student. The MENDEL system instantiates post-Socratic tutoring by structuring genetics problems in order to facilitate their resolution. By this we mean both that problems and student actions are represented in various ways (such as the notational systems) so that the consequences of student hypotheses and actions are made explicit. Clancey (1987), although writing about expert performance, calls this "reifying" the logic of the system. In MENDEL, we are using various notational systems to model and reify student problem-solving actions as well as expert actions. Students therefore see explicit consequences of their hypotheses and actions on various levels of interconnected knowledge. They do not really need the constant intervention of a Socratic tutor in this situation. Rather, they need a problem-solving ADVISOR to help them structure problems so they can eventually solve the problems on their own.

The post-Socratic philosophy outlined above has helped us create a problem-solving environment that encourages students to work through their own difficulties and only receive tutorial advice when they are at an impasse. This philosophy has also helped us recognize a new relationship between students and teachers. In traditional classrooms, problem solving is structured so that the tutor knows the final answer and the solution paths to that answer. This turns problem solving into a rational reconstruction of scientific problem solving. In MENDEL, on the other hand, the tutor and student are equals in terms of their knowledge

(2) the other parent and the offspring with the same variation are heterozygous dominant.

If the SOLVER fired this rule, its frames would be updated and it would continue to fire rules until individuals with the heterozygous condition are identified.

The final stage in the inquiry strategy tree consists of checking the results. This step is included because Collins (1986) found that, even after a problem was apparently solved, experts did an additional cross or crosses along with a statistical test before deciding that they were finished. This checking is done by the firing of definitive cross rules (DCR) and disconfirmation rules (DR). A more detailed description of the SOLVER can be found in Maclin, Allman, Streibel, and Stewart, (1987b).

The TUTOR

Overview

The TUTOR has emerged from a consideration of the activities of human tutors, including their ability to:

1. make inferences about the genetics involved in a particular problem by examining a student's cross data.
2. maintain a history of a student's pertinent actions (including crosses made, and warranted and unwarranted inferences made about the cross data);
3. make inferences about the reasons for a student's problem-solving actions.
4. develop a model of a student's problem-solving performance, including conceptual knowledge;
5. respond to student questions;
6. make decisions on the content and timing of any tutorial advice given to a student;
7. evaluate whether or not a student has benefitted from the advice.

Tutoring

The design of the TUTOR was influenced by a philosophy of tutoring and by our research on the tutoring behavior of experienced genetics instructors. The empirical research is in its early stages and is only now being translated into specific tutoring strategies within MENDEL. The philosophy of tutoring, however, builds on the concept of post-Socratic tutoring (Jungck & Calley, 1985; 1986). Post-Socratic tutoring provides a framework for the interactions between the computer tutor and the student. The MENDEL system instantiates post-Socratic tutoring by structuring genetics problems in order to facilitate their resolution. By this we mean both that problems and student actions are represented in various ways (such as the notational systems) so that the consequences of student hypotheses and actions are made explicit. Clancey (1987), although writing about expert performance, calls this "reifying" the logic of the system. In MENDEL, we are using various notational systems to model and reify student problem-solving actions as well as expert actions. Students therefore see explicit consequences of their hypotheses and actions on various levels of interconnected knowledge. They do not really need the constant intervention of a Socratic tutor in this situation. Rather, they need a problem-solving ADVISOR to help them structure problems so they can eventually solve the problems on their own.

The post-Socratic philosophy outlined above has helped us create a problem-solving environment that encourages students to work through their own difficulties and only receive tutorial advice when they are at an impasse. This philosophy has also helped us recognize a new relationship between students and teachers. In traditional classrooms, problem solving is structured so that the tutor knows the final answer and the solution paths to that answer. This turns problem solving into a rational reconstruction of scientific problem solving. In MENDEL, on the other hand, the tutor and student are equals in terms of their knowledge of the solution and students must take an active part in the important decisions required for scientific problem-solving. Tutors are helpful on the basis of their problem-solving and genetics expertise and not on the basis of their prior knowledge of the answers.

The Student MODELER and ADVISOR

Just as data on expert performance was essential to the development of the SOLVER, data on novice (high school and university undergraduate) problem-solving performance is essential to the development of the student MODELER and the ADVISOR (Albright, 1987; Slack, 1987). It has been important for the design of interfaces that collect data about student hypotheses needed by the MODELER and ADVISOR and for specifying the conditions under which the ADVISOR intervenes and the nature of the advice to give. Research done on student conceptions of chromosome/gene models (Stewart & Dale, 1987) and on the performance of novices when solving GENERATOR problems (Albright, 1987; Slack, 1987) has also provided information on student misconceptions and limited use of hypothesis-testing strategies, as well as specifics about their missed and unwarranted inferences. This information is being used to develop the MODELER'S ability to analyze student performance and to guide the development of the ADVISOR's question-asking and advising capability.

The Student MODELER.

In order for the TUTOR to provide appropriate advice it must have information about the student using the program. It is the function of the MODELER to gather such information, make inferences from it about the student's strategic and conceptual knowledge, and make that information available to the ADVISOR. The MODELER keeps a history of student actions, including: the vials from which organisms were taken for crosses; the making and checking of hypotheses; and the inferences made about the genotypes of individuals or phenotype classes. Some of this information is directly available from a student's interactions with the GENERATOR program or from the various notational system. However, the MODELER will have to do more than accept this data. It will have to be able to recognize patterns in a set of actions done by the student.

The MODELER must also have a knowledge base about typical student conceptions and misconceptions. This type of information, outlined below, comes from current research (Slack, 1987; Albright, 1987; Stewart & Dale, 1987; Stewart, 1987). Ultimately, both rule-based and model-based reasoning are important to successful problem solving. Rule-based reasoning is being developed first; and will add to the MODELER's ability to infer student conceptual knowledge as we continue our research on student problem solving.

A student solving problems will execute a set of actions similar to the SOLVER's inquiry strategy tree that can be modeled as problem-solving rules. However, there should also be conceptual knowledge which underlies the rules. This causal knowledge (for example, of meiosis) is the basis for model-based problem solving. This data will be organized in terms of the major problem-solving steps that we have already identified (See Figure 8).

The ADVISOR.

The ADVISOR, MODELER and SOLVER are a set of closely related programs. The ADVISOR receives information from the SOLVER (about what hypotheses and inferences are justified at any point in a problem solution) and from the student MODELER (about specific actions the student has taken and about hypotheses the student is considering). It then uses this information to provide the student with advice about the problem solution. The advice is appropriate both to the student's current position in the problem solution and to the student's overall background in genetics. We are currently implementing one ADVISOR mode: student-initiated requests for advice. We have done this because in the computer-initiated mode there are two types of decisions that an ADVISOR makes--when to intervene and what assistance to offer once the decision to intervene has been made. By first focusing on the student-initiated mode, we can have a functioning ADVISOR before actually implementing a computer-initiated tutoring strategy.

There are five separate commands available to a student seeking tutorial advice. They are TRACE-STOP, HINT, NEXT-STEP, REVIEW and ANALYSIS (See Figure 1). The first command, TRACE-STOP, is used when a student wants a demonstration of how the TUTOR would solve a particular problem. TRACE-STOP traces all of the SOLVER actions, stopping after each computer-initiated cross to explain the inferences that it has made. In each of the other four commands the computer only acts on the data that the student has produced; it does not make crosses. These four commands can be categorized on two dimensions: one dealing with suggestions about future actions (HINT & NEXT-STEP) or an evaluation of past actions (REVIEW and ANALYSIS), and the second offering advice about specific actions (NEXT-STEP and ANALYSIS) or general strategies (HINT and REVIEW). Figure 8 shows these relationships.

Figure 8 Here

When a student invokes the NEXT-STEP command, the advice will be what the SOLVER will do next, given the data and hypotheses that the student has generated. However, just relaying this informantion to a student may be of limited value. Therefore the student can ask:

1. WHY: and will be shown the specific rule that resulted in the given action.
2. CLARIFY: and will receive a strategy explanation underlying the rule.
3. JUSTIFY: and will receive a support explanation.

Strategy explanations are designed to clarify the rules by explaining them in terms of general strategies applicable to many classes of genetics problems. Support explanations employ genetics content knowledge and examples to justify a rule by describing or illustrating the genetic mechanisms underlying it. A student can use CLARIFY and JUSTIFY more than once for any step. If a student asks for additional clarification more general (although still strategic) explanations will be given. By requesting additional justification he\she will get information about fundamental genetics. For example, a computer program on meiosis can be used by the student to provide this type of support explanation.

When a student invokes the ANALYSIS command, the crosses made during the course of the problem solution are reviewed and he/she is shown what information the SOLVER could extract from each cross. The student is then briefed about the potential significance that each cross has for the problem-solving process and where errors of inference may have have been made. In this mode, the student can also select CLARIFY and JUSTIFY in order to receive additional explanation. The ANALYSIS feature is particularly important in helping students consolidate their problem-solving knowledge. For example, in the course of solving a problem, a student might invent some very useful strategy (e.g., crossing parents with unlike phenotypes for a first cross), yet the power or generalizability of that strategy will not be recognized. By requesting ANALYSIS, useful strategies or inferences that the student made will be revealed.

When a student invokes the HINT command he/she is requesting a specific suggestion for what to do next. The ADVISOR responds to the request with a general hint, and, if that advice is not helpful, it provides increasingly specific hints. HINTS can be given which are appropriate to the actions of performing crosses, making hypotheses about offspring genotypes, or making hypotheses about the genetics of a population as a whole. For example, if the SOLVER determines that it is possible to make an hypothesis about the genetics of the population, then the hints given to the student might proceed from general to specific as follows:

1. Hints to try to generate an hypothesis:
   "Can you make any hypotheses?"
2. General redescription hints to help a student generate an inheritance pattern hypothesis:
   "What do you observe about the initial population?"
   "How many traits are there?" What are they?"
   "How many variations for each trait?" "What are they?"
   "Have you solved other problems having the same number of variations for a trait?"
   "What inheritance pattern hypotheses are consistent with the number of variations?"
   "What if there were three variations instead of two?"
3. Very specific hints about generating hypotheses as stated in the HGR rules.

When students invoke the REVIEW command they receive appropriate comments about their problem-solving performance up to that point. Thus, REVIEW is like ANALYSIS in that it looks back at student actions but it is different in that it provides a general evaluation of a student's performance over the entire problem-solving sequence and does not proceed with a cross-by-cross briefing. Rather, it makes general comments about students' strategies, such as "Most of the parents for your crosses came from the initial population vial." Comments like this can be helpful to a student in future problem-solving sessions. From the combination of these five ADVISOR commands students are able to obtain both strategic and genetics content advice.

Research Related to the TUTOR. The TUTOR has become the central organizing mechanism in MENDEL that orchestrates the problem-GENERATOR, expert-SOLVER, hypothesis-CHECKER, student-MODELER, and problem-solving-ADVISOR. The TUTOR also controls the graphic interface through which the student interacts with these components (See Figure 4). The TUTOR, at present, only instantiates an hypothesis checking tutoring strategy. Other strategies will be added as our research on tutoring proceeds.

We have found that human tutors help students check their hypotheses against the data by asking probing questions about the consistency, completeness, and singularity of the student's hypotheses (Stewart, Maclin & Streibel, 1987). This general tutoring strategy is one well-defined strategy in our system and will help us define which student actions are significant indicators of the presence or absence of hypothesis checking. This tutoring strategy and related performance measures will also form the guidelines of our Hypothesis-CHECKER. The TUTOR, in effect, will act as a control driver that decides what to do and when to do it. The CHECKER is a tool that "checks" students' hypotheses. The check involves determining:

1. if a student has entered an hypothesis,
2. if the hypothesis is legal (does not violate any of the assumptions about making expression charts),
3. if it is complete (or can be completed legally),
4. if it is consistent with the data that has been observed in the population,
5. if it represents a unique explanation of the data, and
6. if all across-trait modifiers have been checked for.

The CHECKER uses information from both the hypothesis and SOLVER data bases to perform these checks. The checks are done in order, and once an hypothesis fails a test, the CHECKER stops processing (later checks are dependent on earlier checks). The CHECKER then returns these results back to the TUTOR without playing any role in deciding what, if any, feedback to provide the student. The TUTOR will then drive the ADVISOR to deliver advice to the student about the hypothesis.

Conclusion

In this paper we have described a research and development project aimed at building an intelligent computer tutor called MENDEL that can be used by high school or university biology students as a tool for learning concepts and problem-solving strategies in transmission genetics. We believe that the role of computers in science education will expand during the next ten years and that intelligent computer tutoring systems will be part of this expansion. It is also our belief that now is an appropriate time to consider how such systems may function in or transform classrooms. We have begun such a deliberation in how we designed the GENERATOR program and in our post-Socratic tutoring philosophy. These two features of MENDEL represent aspects of what we believe good science education ought to be.

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MENDEL's Components

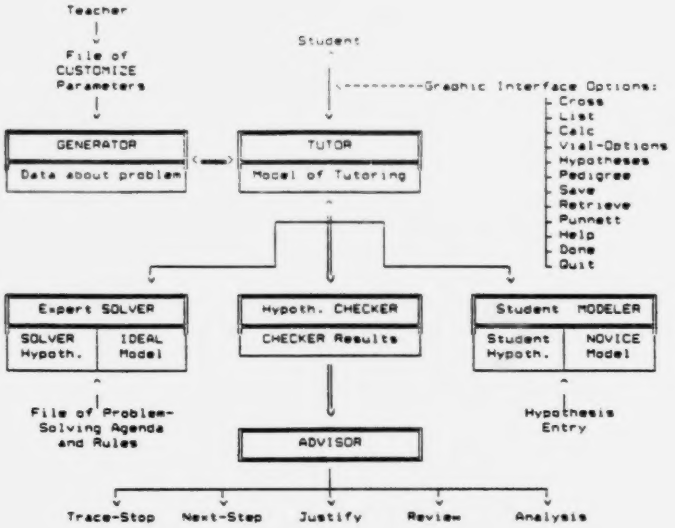
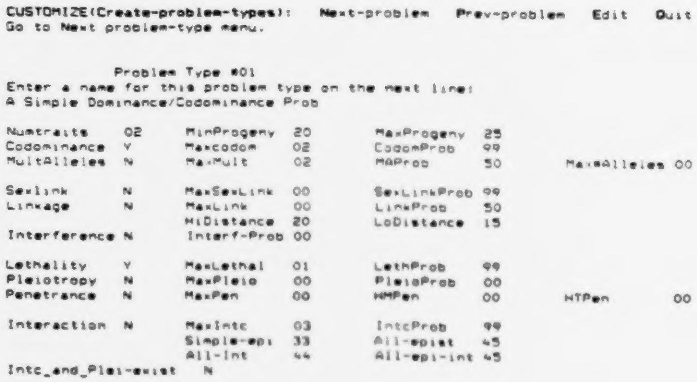

Teacher
File of CUSTOMIZE Parameters
Student
Graphic Interface Options:
Cross
List
Calc
Vial-Options
Hypotheses
Pedigree
Save
Retrieve
Punnett
Help
Done
Quit
GENERATOR
Data about problem
TUTOR
Model of Tutoring
Expert SOLVER
SOLVER Hypoth.
IDEAL Model
Hypoth. CHECKER
CHECKER Results
Student MODELER
Student Hypoth.
NOVICE Model
File of Problem-Solving Agenda and Rules
Hypothesis Entry
ADVISOR
Trace-Stop
Next-Step
Justify
Review
Analysis

Figure 1

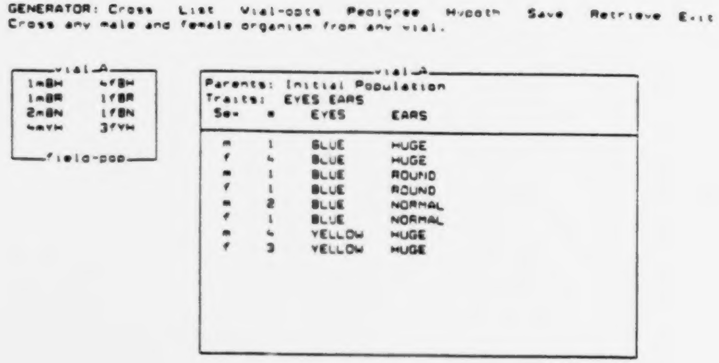
MENDEL's Customize Template



```
CUSTOMIZE(Create-problem-types):   Next-problem   Prev-problem   Edit   Quit
Go to Next problem-type menu.


             Problem Type #01
Enter a name for this problem type on the next line:
A Simple Dominance/Codominance Prob

Numtraits     02     MinProgeny   20      MaxProgeny   25
Codominance   Y      Maxcodom     02      CodomProb    99
MultAlleles   N      MaxMult      02      MAProb       50      MaxAlleles 00

Sexlink       N      MaxSexLink   00      SexLinkProb  99
Linkage       N      MaxLink      00      LinkProb     50
                     HiDistance   20      LoDistance   15
Interference  N      Interf-Prob  00

Lethality     Y      MaxLethal    01      LethProb     99
Pleiotropy    N      MaxPleio     00      PleioProb    00
Penetrance    N      MaxPen       00      HMPen        00      HTPen      00

Interaction   N      MaxIntc      03      IntcProb     99
                     Simple-epi   33      All-epist    45
                     All-Int      44      All-epi-int  45
Intc_and_Plei-exist     N
```

Figure 2

Sample GENERATOR Screen



```
GENERATOR: Cross   List   Vial-opts   Pedigree   Hypoth   Save   Retrieve   Exit
Cross any male and female organism from any vial.

 ----vial A----      ---------------------vial A---------------------
 | 1mBH   4fBH |     | Parents: Initial Population                  |
 | 1mBR   1fBR |     | Traits:  EYES EARS                           |
 | 2mBN   1fBN |     |  Sex   #    EYES      EARS                   |
 | 4mYH   3fYH |     |----------------------------------------------|
 |             |     |   m    1    BLUE      HUGE                   |
 --field-pop----     |   f    4    BLUE      HUGE                   |
                     |   m    1    BLUE      ROUND                  |
                     |   f    1    BLUE      ROUND                  |
                     |   m    2    BLUE      NORMAL                 |
                     |   f    1    BLUE      NORMAL                 |
                     |   m    4    YELLOW    HUGE                   |
                     |   f    3    YELLOW    HUGE                   |
                     |                                              |
                     ------------------------------------------------
```

Figure 3

MENDEL's Inquiry Strategy Tree

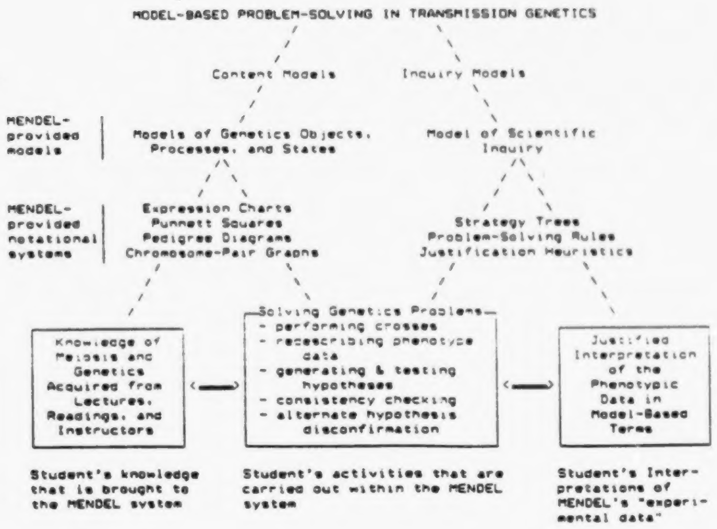

MODEL-BASED PROBLEM-SOLVING IN TRANSMISSION GENETICS
Content Models
Inquiry Models
MENDEL-provided models
Models of Genetics Objects, Processes, and States
Model of Scientific Inquiry
MENDEL-provided notational systems
Expression Charts
Punnett Squares
Pedigree Diagrams
Chromosome-Pair Graphs
Strategy Trees
Problem-Solving Rules
Justification Heuristics
Knowledge of Meiosis and Genetics Acquired from Lectures, Readings, and Instructors
Solving Genetics Problems
- performing crosses
- redescribing phenotype data
- generating & testing hypotheses
- consistency checking
- alternate hypothesis disconfirmation
Justified Interpretation of the Phenotypic Data in Model-Based Terms
Student's knowledge that is brought to the MENDEL system
Student's activities that are carried out within the MENDEL system
Student's Interpretations of MENDEL's "experimental data"

Figure 4

User-Requested Tutorial Options of the ADVISOR Component of the TUTOR*

	General Advice (series of actions)	**Specific Advice** (single action)
Future Actions (SOLVER Data & Hypothesis)	HINT	NEXT-STEP
Past Actions (Student Data & Hypotheses)	REVIEW	ANALYSIS

*Other ADVISOR commands include the TRACE-STOP and DONE options.

Figure 5

Cross Cultural Analysis of Student Understanding of Marine Science and Natural Resource Concepts Related to the Gulf of Maine

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INTRODUCTION:

Science education can be an important part of school curriculum if educators consider the implication of basic science concepts in relation to environmental issues. According to a recent Canadian study by Lien & Walters (1985) education can make an important contribution to the understanding and acceptance of rational resource management especially in today's society of increasing utilization and of decreasing resources.

Science educators in Canada and the United States are faced with similar problems even though the educational systems are somewhat different. In Maine there is no state wide science curricula, so teachers select their own educational materials. In most cases they use generic textbooks with no local meaning. In Canada the provincial government sets the curriculum for each subject and teachers are faced with the problem of making subject content relevant. International environmental issues which appear in the news have a great potential for making science more meaningful in both countries. These issues are often not considered or brought into context with basic science instruction.

The Gulf of Maine, part of the Western North Atlantic, is shared by the US (Maine) and Canada (New Brunswick & Nova Scotia) and has significant impact on Maine's and Atlantic Canada's social, political and economic makeup. Until recently this uniquely productive and valuable resource was used and managed cooperatively by both countries, until decreasing resources led to a maritime boundary dispute. The World court proceedings concerning this boundary dispute in the Gulf of Maine have brought together fundamental and current information on numerous marine science and natural resource concepts, such as physical and chemical oceanography, geology, ecology, resource economics, utilization and management, and decision making. The fact that these basic science concepts can be applied to a region which has two distinct cultures provides an excellent opportunity to investigate cross cultural relationships of students conceptual frameworks and possible sources of misconceptions (Strike, 1983).

In Canada, students favor learning about oceans more than any other environment. They exhibit strong views on the preservation of the ocean environment but have little knowledge on what to base these views (Lien & Walters, 1985). Canadian teachers would like to include marine topics in their classroom but there is a shortage of teaching material. Only 16% of fifth graders and 9% of ninth graders are exposed to marine curriculum (Lien & Walters, 1985). No province in Canada has K-12 interdisciplinary resource material available however, some of the marine resource units and curricula guides developed in the US are utilized by Canadian educators (Graham et al 1985). There is also a lack of marine educator programs, and individuals or agencies with interest in marine education are poorly organized and work in isolation of one another (Lien & Walters, 1985).

Marine education in the United States has been around since the mid sixties when the National Science Foundation (NSF), the Dept. of Education, and Sea Grant provided funds for educating children about the sea (Graham et al 1985). Many of the resource materials developed in marine education use an interdisciplinary approach (Hon 1969, Fortner 1985). By 1978 nearly every coastal state and several inland states had K-12 marine education material, as well as resources for non-formal and continuing education (Goodwin & Schadt, 1978). The office of education and NOAA also cooperate in the development of marine education resources and seminars for teachers (Graham et al 1985).

Within the last 10 years studies in science education have been done on the relationship of students culture to their conceptual framework. Some of these cross-cultural studies have addressed Piagetian reasoning and science concepts (Brown et al ,1977), classification operations (Sintoovongse,1978), proportional and combinatorial reasoning (Kishta, 1979), archaeology as an aid (Smith,1980), language and physics (Logan, 1981), science and word meaning (Isa & Maskill, 1982), and Piagetian psychology (Adey, 1982). Cross-cultural analysis of an international ecological issue appears to be nonexistent

RATIONALE:

Students cognitive framework, concepts and the relationship between them must be understood before introducing new science concepts, otherwise facts maybe acquired by rote memorization and arbitrarily incorporated into the learners cognitive development. To understand something, one must integrate it with already existing schemata (Carey, 1986). The paradox of science education according to Carey (1986) is that its goal is to impart new schemata to replace the students extant ideas, which differ from the scientific theories being taught.

The theoretical perspective for this study is guided by the following: (1) before assessing student knowledge in any domain, the major concepts and organizing principles of the knowledge domain should be identified (Champagne & Klopfer, 1984); these principles should be broad and inclusive, stressing conceptual relationships and meaning rather than isolated facts, (2) the assessment of student knowledge through interviews provides a more comprehensive picture of student understanding of concepts and conceptual relationships than other more frequently used assessment techniques, such a multiple choice tests (Novak & Gowin , 1984) ; (3) the assessment of student knowledge in a given domain can provide information useful in the design of curricula and educative materials that address the conceptual problem areas and misconceptions of students directly and that introduce new and difficult concepts in ways that will facilitate nonarbitary (meaningful) linkage of those concepts to existing relevant knowledge in students cognitive structure (Ausubel et al 1978); (4) if teaching is to become meaningful what knowledge and misconceptions students already have must be first determined (Novak, 1984).

RESEARCH QUESTIONS:

This research addresses basic issues in environmental education by asking the following questions: (1) What science and natural resource concepts do 4th, 8th, and 11th grade students in Atlantic Canada possess concerning the Gulf of Maine as a marine ecosystem and a shared resource? (2) Does student comprehension of these concepts and conceptual relationships change between grades? (3) how do these results compare to a similar study in Maine?

METHOD:

The research topic was selected by the authors following a news media survey of current events related to marine science and environmental education in Maine and Canada. The major concepts and organizing principles were explicated by a previous study in which students in science and environmental education at the University of Maine conceptually analyzed primary resource documents related to the Gulf of Maine (Brody & Koch, 1986). This analysis subsequently yielded fifteen major content principles (Table 1) which the research group considered to be essential for an understanding of the marine science and natural resource issues in the Gulf of Maine.

In this study, modified clinical interviews as described by Novak & Gowin (1984) were conducted to ascertain what knowledge students have of marine science and natural resource issues. in the Gulf of Maine. Approximately 30 students from six schools in New Brunswick (NB) (St. George located on the Bay of Funday 35 km from the Maine border) and Newfoundland (NF) (Avalon peninsula) were interviewed; ten 4th graders, ten 8th graders and ten 11th graders. Although the schools were selected primarily on the basis of proximity and convenience, both urban and rural schools representing a range of socio-economic levels were represented.

Interview details:

The interviews were guided by general lead-in focus questions, developed from the previously constructed concept maps (see Novak & Gowin, 1984 ch7). Lead-in questions were followed by more specific probing questions based on the concept maps, to determine the presence (or absence) of concepts and misconceptions, and the students ' overall level of understanding of the major principles. Interview props were used to sustain student interest and focus their attention each interview was audiotape recorded and lasted approximately 20 minutes. The tapes were subsequently evaluated to determine the presence or absence of concepts and misconceptions in relation to each major content principle. Student knowledge of the content principles was scored on the following scale:

TABLE 1. Content principles based on primary research and secondary sources used in design and analysis of interviews from Brody and Koch 1986.

Number	Major Content Principle
1	The Gulf of Maine is separated from the Atlantic Ocean by Georges Bank and is bordered by the eastern coastlines of the U.S. and Canada.
2	The ocean bottom is continuous with the continent, has a slope, gets progressively deeper, and is interrupted by bottom features such as channels, banks and shoals.
3	Ocean water in the Gulf of Maine is characterized by low temperatures and salinity, which is primarily the result of freshwater inputs from the continent.
4	Ocean water in the Gulf of Maine is nutrient rich.
5	Water in the Gulf of Maine moves because of wind driven waves and currents, river inputs and tides, which collectively result in upwelling and uniformally mixed waters.
6	Energy flows through this system from the sun to plants to animals.
7	Within the system, plants capture light energy and use it to make food.
8	Within the system, plants and animals interact in a complex food chain and web.
9	The Gulf of Maine contains valuable living and nonliving resources that man has exploited over several generations.
10	Renewable resources in the Gulf of Maine (fish, seals, lobsters, seaweed) have been harvested using a variety of traditional techniques (drags, traps,nets).
11	Non-renewable resources, such as hydrocarbons and gravel, are being considered for exploitation.
12	The Gulf of Maine is also considered valuable for recreation, research, tourism, and other non-consumptive resource use.
13	The Gulf of Maine has traditionally been utilized as a common resource by many nations, and currently there is a conflict over the future of these resources.
14	Disputes over resources can be negotiated by concerned parties through mutually agreed upon decision-making (negotiation).
15	Inorder to insure a balanced system, management strategies based on conservation and utilization must be practiced.

3- Fully complete conception: Student recognized and understood the meaning of the entire major content principle.

2- Partially correct conception: Student recognized and understood more than half of concepts and propositions in content principle.

1- Little conception: Student recognized or understood less than half of concepts and propositions from content principles.

0- Completely missing concept: Student was unable to give a clear or meaningful explanation of any concepts within the major content principle.

M- Misconception: Student drew conclusions or gave explanation based on concepts unrelated to given sets of events.

Student's correct concepts, missing concepts, and misconceptions for each content principle was tabulated for subsequent analysis. The mean interview score for each principle and the grand mean interview score on all 15 principles were calculated for each grade level. For this purpose, misconceptions were given the same rating as completely missing concepts (0). While some researchers may argue that misconceptions represent knowledge that interferes with learning and should be scored negatively, others contend they may provide some useful cognitive structure and should be scored positively. These positions are hard to document explicitly, and it is even more difficult to determine just how positively or negatively a misconception should be scored. Consequently , a score of zero to student misconception was assigned to represent an intermediary position on these views. One-way analysis of variance and Duncan's multiple range test were used to determine whether the mean score of 4th, 8th and 11th graders on each content principle were significantly different from one another. Similar analyses were done to determine significant differences between the grand mean score of each grade level. The same tests were also used to see if any significant difference occurred between the Newfoundland and New Brunswick students for each principle, and all principles combined for a grand mean.

Generalized student statements of correct, and missing concepts were tabulated for each principle. The percentage of all students interviewed who fell into these categories was compared to the Maine study of Brody & Koch (1986). The misconceptions which occurred for both studied were also compared.

RESULTS and DISCUSSION

Figure 1 and table 2 show that the mean score for each principle at each grade level was relatively low. The highest mean score on any single principle (2.8 + 0.4) was obtained by 11th graders on principle 10 (renewable resources and harvesting technique).

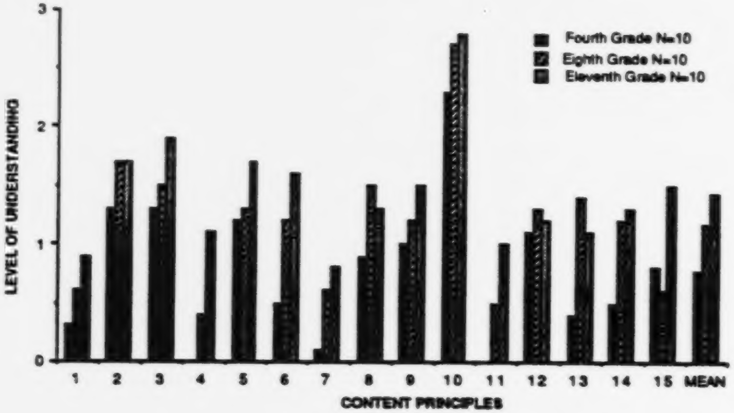

Figure 1. Mean interview scores of 4th, 8th and 11th grade Canadian students on marine science and natural resource concepts related to the Gulf of Maine.

Students at all grade levels had practically no understanding of principle 1 (the Gulf of Maine and its boundaries), principle 4 (nutrients), principle 7 (plants capture sunlight to make food, and principle 11 (non-renewable resources). The comprehension of these principles however, did improve with grade level. Grade 11 students understood significantly more than grade 4 students. Generally students in the 11th grade understood more concepts in each principle than 4th graders. The overall grand mean, however, for each grade level and each principle indicates that students, on the average, understood only a few science and natural resource concepts and their relationships, concerning the Gulf of Maine. Table 2 also shows that there was considerable variability associated with the mean score for many of the principles. This indicates that at a given grade level students varied in comprehending the concepts of the principle.

Table 2.

Mean score of 4th, 8th, and 11th grade students on each content principle and all principles combined (grand mean).* = significant difference, $P < 0.05$ ANOVA and Duncan's Multiple range; NSD = no significant difference between means. N=30

	Mean score (+ SD)			Grade level comparison		
Content Principle	4th	8th (N=10)	11th (N=10)	4 &8 (N=10)	4 &11	8 &11
1	.3(.5)	.6(.5)	.9(.7)	NSD	*	NSD
2	1.3(.5)	1.7(.5)	1.7(.7)	NSD	NSD	NSD
3	1.3(.5)	1.5(.5)	1.9(.6)	NSD	NSD	NSD
4	0	.4(.7)	1.1(.7)	NSD	*	*
5	1.2(.4)	1.3(.7)	1.7(.7)	NSD	NSD	NSD
6	.5(.7)	1.2(.8)	1.6(.7)	*	*	NSD
7	.1(.3)	.6(.8)	.8(1)	NSD	NSD	NSD
8	.9(.6)	1.5(.8)	1.3(.9)	NSD	NSD	NSD
9	1.0(0)	1.2(.4)	1.5(.5)	NSD	*	NSD
10	2.3(.7)	2.7(.5)	2.8(.4)	NSD	NSD	NSD
11	0	.5(1)	1(1)	NSD	*	NSD
12	1.1(.3)	1.3(.5)	1.2(.4)	NSD	NSD	NSD
13	.4(.5)	1.4(.7)	1.1(.6)	*	*	NSD
14	.5(.5)	1.2(.8)	1.3(.9)	NSD	*	NSD
15	.8(.4)	.6(.7)	1.5(.5)	NSD	*	*
TOTAL	.78(.2)	1.18(.2)	1.43(.4)	*	*	NSD

Table 3 shows the mean and standard deviation of New Brunswick and Newfoundland students for each principle. There was no significant difference between the two provinces for principles 2-15. In principle 1 (knowledge of the Gulf of Maine) Newfoundland students comprehended more of the concepts than did New Brunswick students.

Table 3
Mean score of New Brunswick (NB) and Newfoundland (NF)students on each content principle and all principles combined (grand mean).*= significant difference, P< 0.05 ANOVA and Duncans Multiple range N=30

Content Principle	NB (N=18)	NF (N=12)	
1	.39	.92	*
2	1.67	1.42	
3	1.61	1.5	
4	.39	.67	
5	1.39	1.41	
6	1.16	1.00	
7	.61	.33	
8	1.16	1.33	
9	1.22	1.25	
10	2.55	2.67	
11	.27	.83	
12	1.27	1.0	
13	1.05	.83	
14	.88	1.17	
15	.78	1.12	
Grand Mean	1.10(.42)	1.12(.43)	

Table 4 shows generalized correct concepts for each content principle, and the percentage of all students who understood at least these concepts for New Brunswick/Newfoundland and Maine (Brody & Koch, 1986) students. The remaining students did not possess even these limited sets of concepts. This table also compared the Canadian data to the Maine data from Brody &Koch (1986).Differences of 20% or greater exist for principles 3, 5, 8, and 13. In each case the Maine students comprehended more of the concepts in each principle. For principles 9, 10, and 12 more students in Atlantic Canada understood these concepts in the content principles.

Table 4
Generalized student correct concept for each content principle and % of all students interviewed who understood at least these concepts in each principle

Content Principle	Correct Concept	% of all students Maine (N=221)	NB &NF (N=30)
1	The Atlantic Ocean is bordered by the eastern coastlines	66.8	50.0
2	The ocean bottom is continuous with continent slope, gets progressively deeper and is interrupted by bottom features.	89.9	76.7
3	Ocean water is characterized by low temp., has salinity and rivers and streams run into the ocean.	78.0	43.3
5	Ocean water mixes and materials move around; waves are wind driven and there are tides caused by the moon's gravity.	88.0	26.7
6	Plants need light and some animals feed on plants.	43.3	43.3
7	Plants need light and some animals feed on plants.	43.3	43.3
8	Plants and animals interact in food chains and webs.	86.5	63.3
9	We have been fishing in the ocean and there are resources in nature we use.	82.0	100
10	We fish for shellfish and fish with nets and traps	93.0	100
11	There is a possibility there are other resources off our coast (oil).	35.1	30.0
12	We use the ocean for swimming, boating and beauty.	82.1	100
13	Conflicts over resources exist.	39.0	20.0
14	Disputes over resources might be solved by people.	77.8	73.3
15	Resources can be conserved and utilized	71.3	73.3

Table 5
Missing Concepts for each content principle and percentage of all students interviewed who were missing these concepts.

Content Principle		% of all students Maine (N=221)	 NB &NF (N=30)
1	Gulf of Maine separated from Atlantic by Georges Bank.	94.0	96.7
2	Channels, banks, shoals; distribution and size of bottom features.	93.8	73.3
3	Sources of salinity, concentration and dissolved gases.	98.9	90.0
4	Nutrients and their role in ecosystem.	99.3	70.0
5	Current patterns, upwelling, uniform mixing and distribution of nutrients.	99.5	96.7
6	Energy flow and conversions in marine ecosystem.	97.0	94.0
7	Microscopic algae for primary productivity plants use solar energy to make food.	94.9	87.0
8	Marine species and distribution, complexity of relationships; examples of food chain relationship	87.0	30.0
9	Non-living marine resources/exploitation over time.	100.0	33.0
10	Renewable natural marine resources.	89.2	30.0
11	Future exploitation of non-renewable marine resources.	99.4	94.6
12	Oceanographic research	96.4	100
13	Future exploitation of marine resources, commonresources exploited by many nations, knowledge of conflict and utilization process.	97.0	93.3
14	Mutually agreed upon decision-making.	96.2	90.0
15	Balanced system, management, conservation utilization.	96.7	73.3

Since the mean score for each content principle at each grade level was below a two (partially correct response) except principle 10 (marine renewable renewable resources and harvesting technique) where the grand mean was 2.6 + .6 there were crucial concepts in each principle which students were missing. Table 5 summarizes some of the more complex and specific missing concepts, and the percentage of students missing these concepts for the Canadian and Maine students. A 20% or greater difference occurred between the Canadian data and the Maine data in principles 2, 4, 8, 9, 10, and 15 where in each case Maine students had more missing concepts . The most striking differences were in principles 8, 9, and 10 dealing with marine species relationships and resources .

This is comparable to the Lien & Walter (1985) Canadian study on 5th and 9th graders knowledge and attitude about the ocean. They make some general comparisons between Canadian students and American students knowledge of the ocean based on studies by Howe & Prince (1976), Leek (1980), Fortner & teats (1980), and Fortner & Mayer (1983). No direct comparisons were able to be made as studies were different however, Lien & Walters (1985) state: that Canadian students probably , overall, may fare as well as or better in marine knowledge tests than American students.

Table 6 reveals some of the misconceptions which occurred during the interviews. In total there were 27 different misconceptions but Table 6 only records misconceptions that occurred in 10% or greater of the students.

Table 6. Misconceptions of students in Canadian sample
(* common misconceptions in Maine sample)

(1) Plants do not need light.*
(2) The ocean is a limitless resource.*
(3) There are no political boundaries in the ocean.*
(4) There are no seaweeds in shallow water.
(5) There are seaweeds all over the ocean.
(6) Seaweeds do not grow on rocks.
(7) Seaweeds are not living.
(8) Seahorses live in the Northern ocean.
(9) Ocean water (Gulf of Maine) is more salty inshore.
(10) The waters off the east coast of North America are called the Pacific.

The concepts and conceptual relationships for the major content principles are going to be influenced by the misconceptions. This is very apparent in the students misconceptions about plants (seaweeds) and their role in the marine ecosystem.

The first three misconception were found in the Maine investigation as well. At least 50% of the Maine students had these misconceptions as well as believing coral reefs exist throughout the Gulf of Maine. No misconception in the Canadian study occurred more than 20% (more salty inshore).

CONCLUSION:

Several general conclusions can be drawn from this investigation: (1) students learn a few basic marine science and resource concepts in school; (2) there is further assimilation of new concepts and differentiation of existing concepts as these students progress through the grades; (3) generally, the level of understanding of basic concepts related to marine ecosystem dynamics and decision making processes is low; (4) overall it would appear that the Canadian students know more about marine science and natural resource concepts with a lower percentage of misconceptions than the Maine students. The Maine students, however, did know as much if not more scientific facts where as Canadian students comprehended more concepts relating to socio-economic factors. It would have been expected that Maine students would have scored higher than the Canadian students because of the amount of marine curricula available in the United States. It is therefore apparent from this study that knowledge of marine-related concepts and issues are gained through an array of experiences both in and outside of the school environment.

This study has revealed that there is a difference in knowledge, understanding and misconceptions between the two cultures of Maine and Atlantic Canada. The results also showed variability with student knowledge of any one content principle. Research on the possible factors which explain this variability will be investigated in the next phase of this research. The cultural factors (influences) which led to misconceptions as well as why there is a difference between Maines students' comprehension of principles and the Canadian students' understanding of these concepts will also be investigated.

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A Study of Conceptual Change in the Content Domain of the Lunar Phases

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INTRODUCTION

According to conceptual change theory, "accommodation" is believed to be analogous to the paradigm shift described by Kuhn, in that an individual's central concepts are replaced by new ones that explain the known observations and allow for the prediction of new phenomena (Posner et al, 1982). Conceptual change theorists suggest that instruction be designed to facilitate accommodation, since it is assumed that students often begin with "alternative framework" central concepts that are erroneous.

The first purpose of the study reported here is to question the generality of this "alternative framework" assumption and therefore the appropriateness of "teaching for accommodation" in all science content domains. To answer this question, college students' prior knowledge of the astronomical content domain of lunar phases was examined and then characterized as to their types of theories, as well as to the completeness of both their theoretical and observational knowledge. Completeness was considered important, since it is a significant quantity on which student models vary, and it may be considered an indication of the strength of a model.

A second purpose of this study is to see what changes occur in students' knowledge after direct exposure to the domain of observation (the lunar phases over the course of a month), and to see if there is any relationship between the completeness of a student's prior knowledge and whether the student maintained their prior model or switched to a different model.

To answer these questions, a second test was given after exposure to the changing appearance of the moon. Changes in the prior knowledge were described as concept change (accommodation) or concept elaboration (assimilation.) The completeness of student's prior knowledge for students who accommodated was compared to the knowledge completeness for students who assimilated.

METHOD

Subjects

The subjects were students (N=61) in an elementary descriptive astronomy course offered at St. Cloud State University, located in rural Minnesota. These students represent a variety of ages and academic levels. As with their counterparts in similar courses and at similar (comprehensive) universities throughout the country, most were not science majors, and few had taken other college science courses.

Instruction

Students were given observation forms on which to record observations, compasses, and explicit instructions for observing the moon. Each student was assigned a time at which they were to observe the moon, on a daily basis. After one full month of observations, the instructor had the students summarize the data and then gather in groups to think about models that might explain that data.

Instruments

Tests designed to elicit students' knowledge of the phases of the moon through written explanations and drawings were given to the students before instruction commenced. These tests were structured to cover the discipline-defined domain of explanation and observation in detail, but open ended enough to allow for individual expression. Questions, which asked for detailed written statements and drawings to explain answers, pertained to the domain of observations, theory of the phases, and explanation and prediction of lunar phase phenomena.

After making and discussing their observations and theories, students were given a second test (called the "midtest", since a final posttest not reported here was also administered after additional instruction was completed) that asked them once again to describe the lunar phases and to describe the theory that they believe best explains these phases.

ANALYSIS

1. Students' statements were broken down into propositions and numbered for future reference.

2. Model Classification: These propositions were then compared, on a student by student basis, to the complete set of propositions as defined by the discipline and described in Table 1. These propositions were derived from the standard astronomy textbooks, Abell's (1982) *Exploration of the universe*, and Pasachoff's (1987) *Astronomy: From the earth to the universe.*

Alternative framework models were compared to sets of propositions that provided a plausible, alternative explanation. For example, one such alternative set has been unofficially labeled the "eclipse" model, which says that the phases of the moon are caused by the shadow of the Earth. This model is described in Table 2.

Students who offer certain key propositions definitive of the discipline model were placed in the "correct" model group. These key propositions included the notion that the Earth moves around the sun, at least

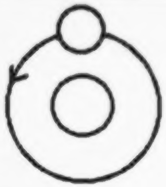
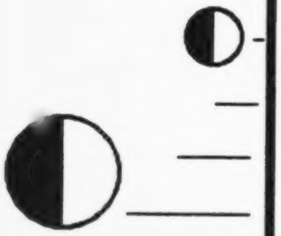
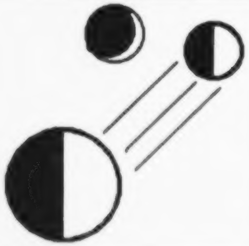
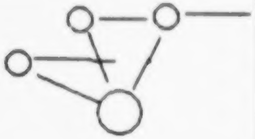
Propositions	Diagram
1. The moon orbits the Earth.	
2. The half of the moon facing the sun is illuminated.	
3. The part of the half that we see determines the phase.	
4. The relative position determines the part of the half we see.	

Table 1. Discipline model propositions.

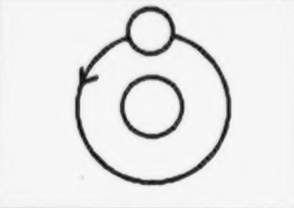
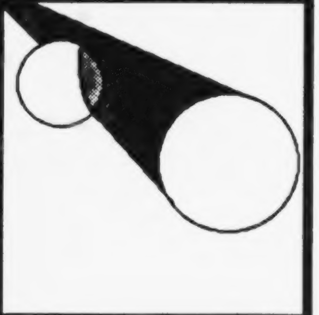
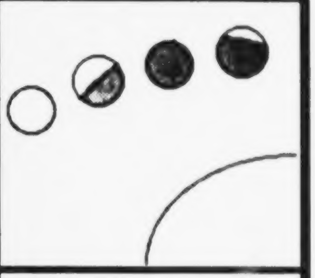
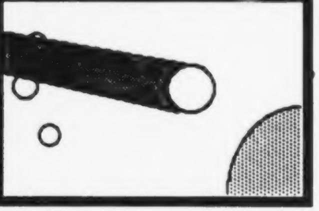
Propositions	Diagram
1. The moon orbits the Earth.	
2. The part of the moon in the shadow of the Earth is dark.	
3. Phases are determined by the extent to which the moon is in shadow.	
4. The extent to which moon is in Earth shadow is determined by the position of Earth, moon, and sun.	

Table 2. Eclipse model propositions.

one additional proposition from the list of propositions in table 1, and a consistent and correct explanation of at least one phase.

Students who have key propositions definitive of an alternative model, such as the eclipse model described above, were placed in the appropriate alternative model group . For example, to be classified as an eclipse model, the explanation must include a reference to the blockage of sunlight to the moon by the Earth. To be classified as a "heliocentric" model, the explanation must include a reference to the moon orbiting the sun.

Students whose knowledge does not meet the key criteria for any specific group, but nevertheless includes some correct facts about the phases of the moon, are placed in the "fragments" group.

Students whose knowledge is not only fragmentary, but does not seem to be a part of any potentially plausible model, are placed in the "other" group.

Students who appear to have no knowledge whatsoever are placed in the "No model" group.

Propositions were further defined as *core* and *derived*. Propositions were considered core if they related to the *cause* of the lunar phases. Propositions were considered derived if they related to the further *explanation* of specific phases in terms of the model as defined by the core concepts.

The core propositions as defined by the discipline can be found in virtually all astronomy texts, and were the ones mentioned in table 1. Examples of some derived propositions as defined by the discipline can be found in table 3.

The alternative core propositions for the eclipse model were mentioned in table 2. Examples of some alternative derived propositions are listed in table 4.

3. Propositions were analyzed for completeness. (See the next section for further details.)

4. Steps 1 through 3 were repeated for the midtests.

"During new moon we can't see the dark side because it is turned away from us."

"At crescent we see a little bit of the lit part."

"When the moon is between us and the sun, the side that is bright is facing away from us, so we can't see the moon. This is new moon."

Table 3. Additional "derived" propositions from discipline model.

"At new moon the Earth blocks the sun's light from getting to the moon."

"Full moon is when the Earth comes fully out from the shadow of the moon."

"Crescent moon is when we see a little bit of the moon that is not covered by the Earth's shadow."

Table 4. Additional "derived" propositions from the eclipse model.

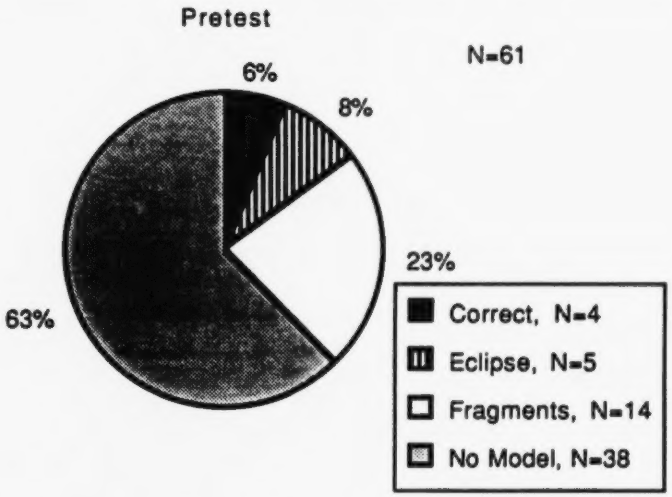
RESULTS

Distribution of Pretest Model Types

As seen in figure 1, aside from a small number of students who had the correct model, (N=4), and a small number of students who had an alternative (eclipse) model,(N=5), most students began instruction with either fragmentary knowledge (N=14) or no knowledge whatsoever (N=38) about the cause of the phases of the moon.

The small number of students with alternative models indicates that in the case of the lunar phases, teaching for accommodation may not be called for.

Figure 1. Breakdown by model type for the pretest.



Completeness

Completeness here refers to the fraction of the total possible core and derived propositions, as defined either by the discipline or by a plausible alternative model, that were represented by the student. A 100% complete set of propositions would explain the cause of phases, and provide an additional explanation for each individual phase.

Propositions for complete alternative propositional sets, (including both core and derived concepts), although they cannot be found in textbooks, can be easily imagined that are plausible, consistent, and powerful in their explanatory power. (See Table 2 for the case of the eclipse model.)

For each student, and then summarized for each model class, the percent of the discipline-defined core, discipline-defined derived concepts, alternative model core concepts, alternative model derived concepts, and the domain of observations, were calculated.

As can be seen in figure 2, students varied in the degree of completeness of their core and derived concepts. Students with correct models had the most complete core (73%) and derived (59%) propositions. Even those students who began instruction with the wrong (eclipse) model or fragmentary knowledge had some propositions (24% for eclipse, 34% for fragments) from the core of the correct model (shown as black in figure 2) that could be used to build on in future instruction.

There was only slight variability as to the specific propositions that were present in two different individuals with roughly the same core completeness score and the same "correct" model type. Variability might have been greater had it not been for the fact that a minimum of several key propositions were needed to define the model type group in the first place, and the fact that some propositions tend to come in clusters.

Students classified as having "fragments" typically were aware of the fact that the lunar phases were related to the moon orbiting the Earth, but were lacking any understanding of how this could *cause* the phases.

As can be seen in figure 2b, students with the eclipse model had alternative model cores that were fairly complete, but alternative derived concepts that were less so. This can be explained by the fact that it is somewhat more difficult to develop a complete set of explanations for the eclipse model.

Figure 2a. Completeness.

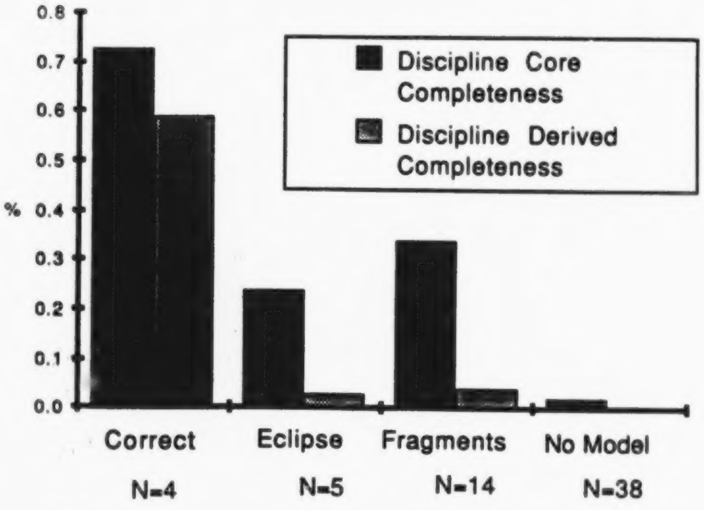
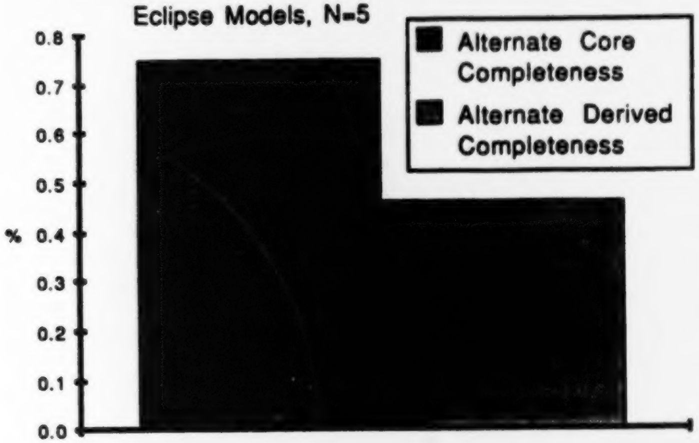
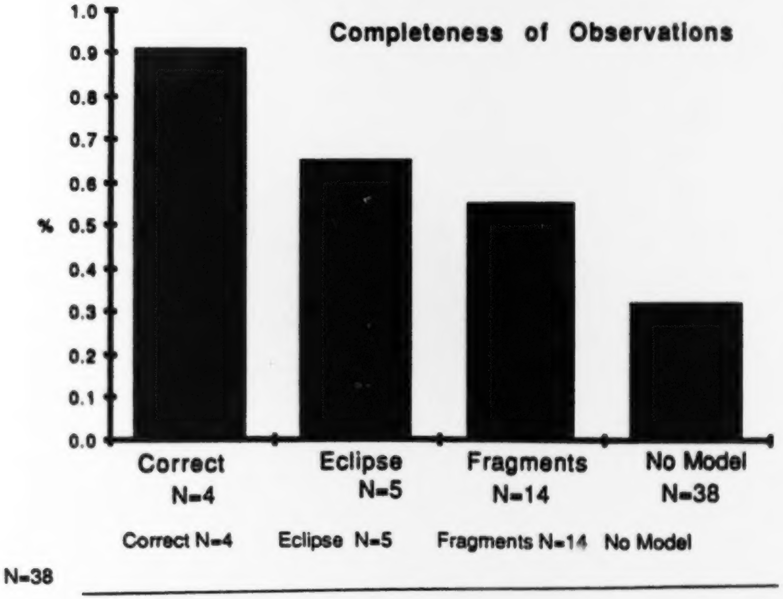


Figure 2b. Completeness for eclipse models.





As seen in figure 3, students varied in the completeness of their prior knowledge of the phenomena (or domain of observations) of the phases. Those who began with the correct model were most complete (90%), those who began with the eclipse model were next (65% completeness), those who had fragments knew 55% of the observational domain, and those with no model knew only 35% of the observational domain. It seems that there is a definite correlation between having a model and being familiar with the observations.

The Effect of Observations on Student Models

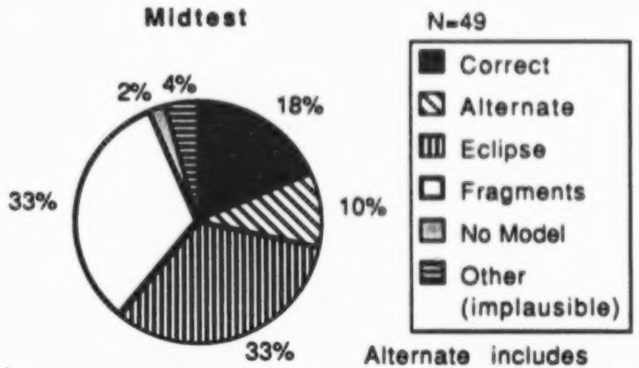
After directly observing the phases, and discussing possible explanatory models in small groups, the students were given the midtest. The midtest responses were very different from the original, pretest responses. (Refer to figure 4, below.) Many more students had fragmentary knowledge or eclipse models. More students had the correct model. Some students had plausible alternative models other than the eclipse model. These included the idea that the phases are due to the moon orbiting the sun (it is new when behind the sun), and the interesting notion that the phases are the result of two moons (a new and a full) that slowly occult each other.

Another alternative model was one that combined elements of the eclipse model with elements of the correct model. In one such model, the moon was portrayed as crescent when it was nearly opposite the sun, as it would be in the eclipse model. When the moon continued in its orbit until it was between the sun and Earth, it became crescent once again, as would be expected with the correct model.

Twelve out of the original sixty-one students did not return for the midtest, either because they had dropped the course or because they skipped class that day.

The large number of students who acquired incorrect knowledge (the eclipse or other alternative models) as a result of making and discussing observations suggests that it might be helpful to give advanced organizers before the observations commence. It also suggests that teaching for accommodation may at times be appropriate not at the very beginning of instruction, but at certain points during instruction.

Figure 4. Models of students as revealed by their midtests, after observing the phases and discussing their observations and models.



Alternate includes Heliocentric, Eclipse/Correct, Double Moon.

The Change in Models.

Refer to figure 5 for a pictorial representation of the model changes experienced by the students. Those starting with correct models were found, by the time of the midtest, to have either correctly assimilated new information, incorrectly assimilated eclipse propositions into their old models to form an eclipse-correct blend, or lost information to be reclassified as "fragmentary".

Students starting with eclipse models either accommodated to the correct model, elaborated upon their eclipse models, acquired fragments of the correct model, or assimilated correct propositions into their original eclipse model to arrive at an eclipse-correct blend.

Students starting with fragments acquired either eclipse models, more fragments of the correct model, the correct model, or alternative models. Two students did not return for the midtest.

Most students starting with no model either did not return for the midtest, acquired fragments, or acquired the eclipse model. A few acquired the correct model, other plausible models, and other implausible ideas.

Of the twelve students who did not return for the midtest, ten had no model and two had fragments on the pretest.

Model Change as a Function of Completeness

It seems plausible that students who had well developed, complete models, whether they were right or wrong, would be less likely to spontaneously change their models than students with very incomplete models.

As can be seen in figure 6a and 6b, students who maintained their models did have more complete cores, derived propositions, and knowledge of the observations than those who shifted their models.

Figure 5a. Model changes for students beginning with correct models.

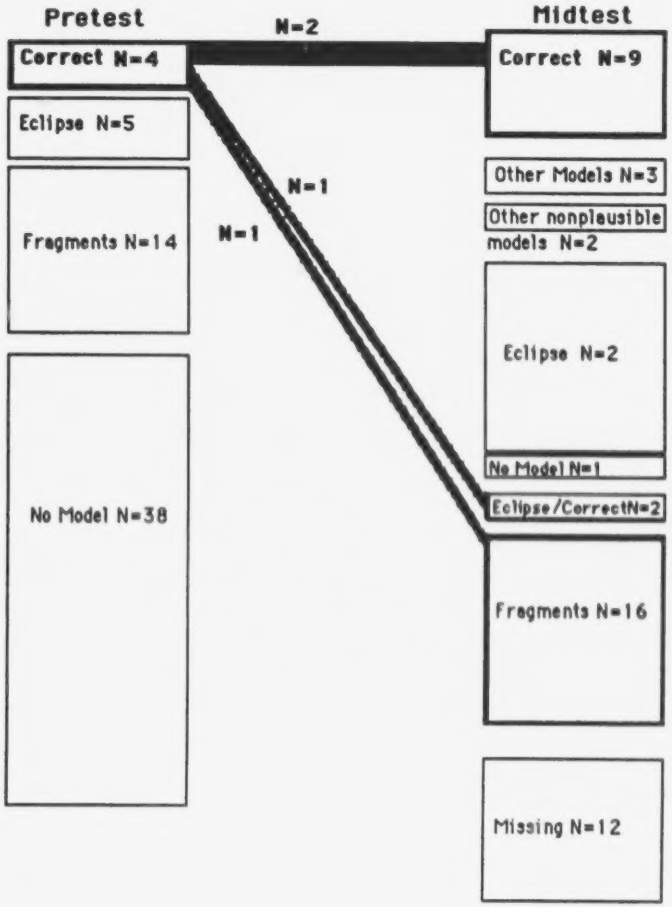
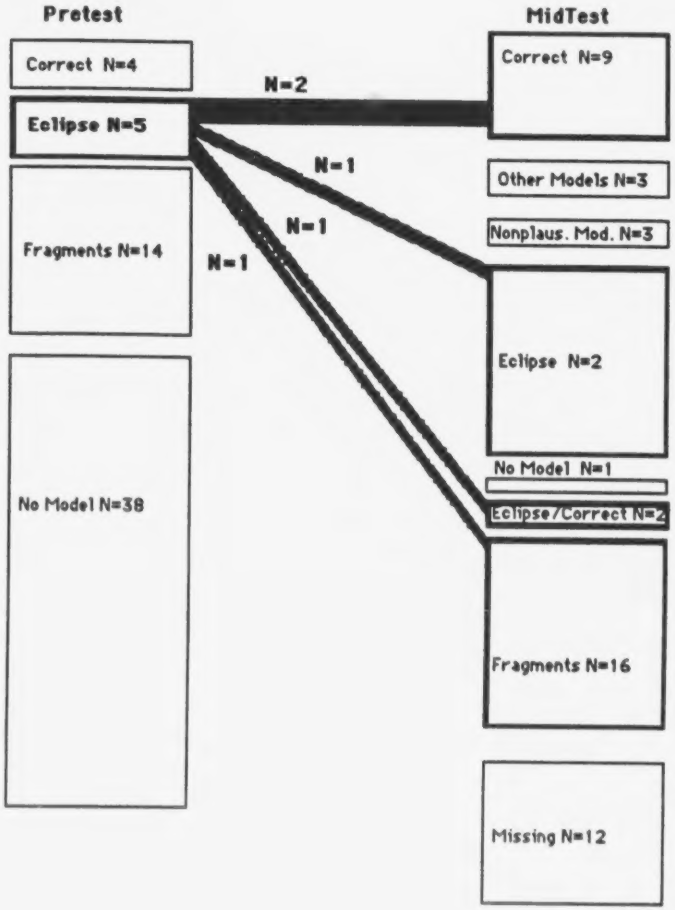
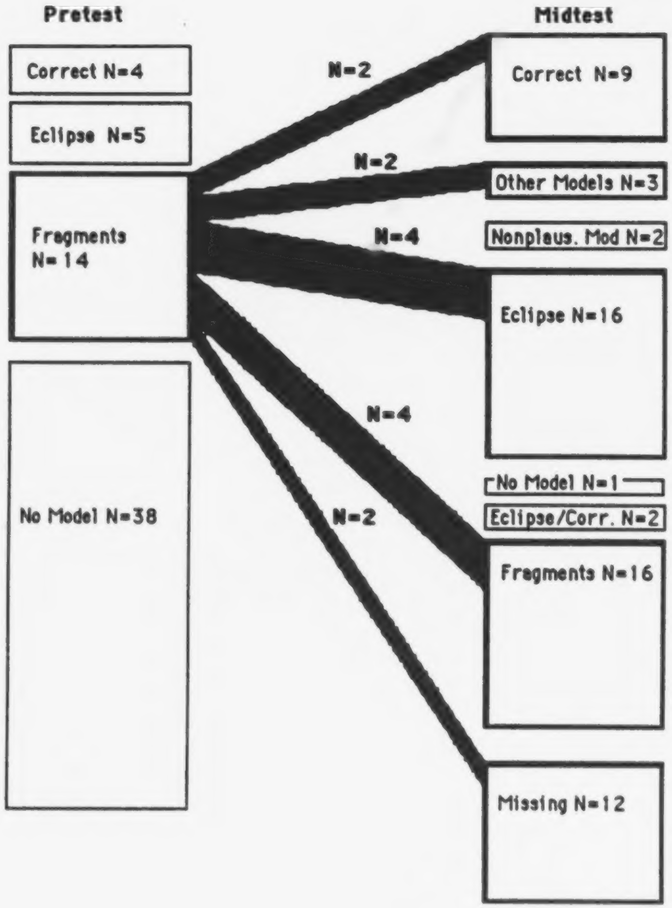

Pretest
N=2
Midtest
Correct N=4
Correct N=9
Eclipse N=5
Other Models N=3
N=1
Other nonplausible models N=2
Fragments N=14
N=1
Eclipse N=2
No Model N=1
No Model N=38
Eclipse/CorrectN=2
Fragments N=16
Missing N=12

Figure 5b. Model changes for students beginning with eclipse models.


Pretest
MidTest
Correct N=4
Correct N=9
N=2
Eclipse N=5
N=1
Other Models N=3
N=1
Nonplaus. Mod. N=3
Fragments N=14
N=1
Eclipse N=2
No Model N=38
No Model N=1
Eclipse/Correct N=2
Fragments N=16
Missing N=12

5c. Model changes for students beginning with fragments.


Pretest
Midtest
Correct N=4
Eclipse N=5
Fragments N=14
No Model N=38
N=2
N=2
N=4
N=4
N=2
Correct N=9
Other Models N=3
Nonplaus. Mod N=2
Eclipse N=16
No Model N=1
Eclipse/Corr. N=2
Fragments N=16
Missing N=12

5d. Model changes for students beginning with no model.

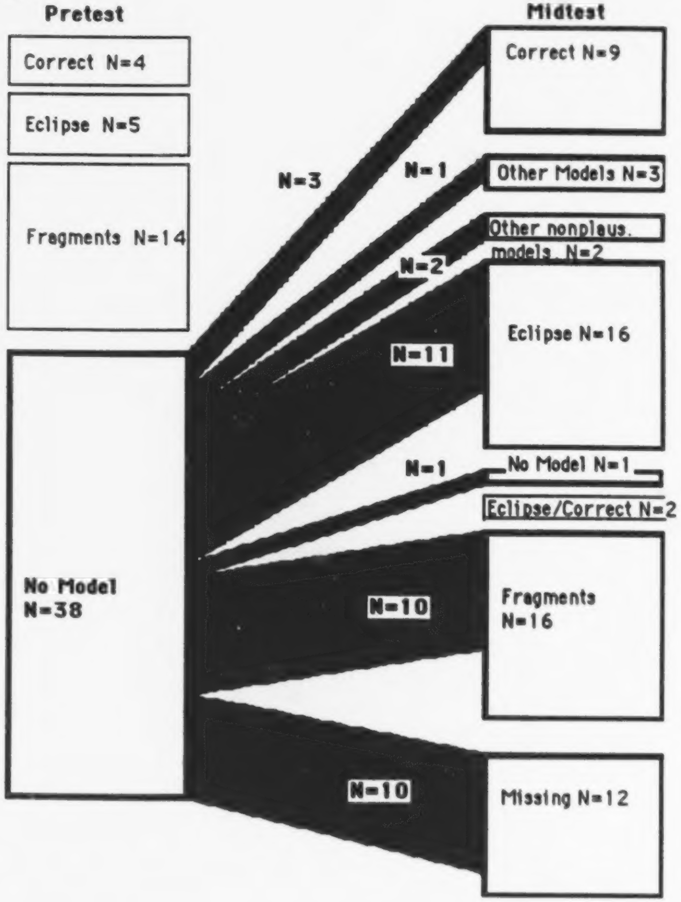

Pretest
Midtest
Correct N=4
Eclipse N=5
Fragments N=14
No Model N=38
N=3
N=1
N=2
N=11
N=1
N=10
N=10
Correct N=9
Other Models N=3
Other nonplaus. models N=2
Eclipse N=16
No Model N=1
Eclipse/Correct N=2
Fragments N=16
Missing N=12

Figure 6a.
Completeness as a function of Model Retention or Model Shift for people starting with correct model.

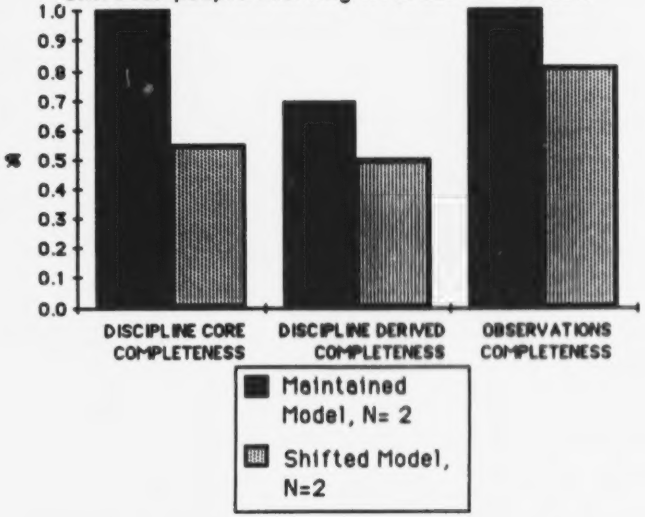
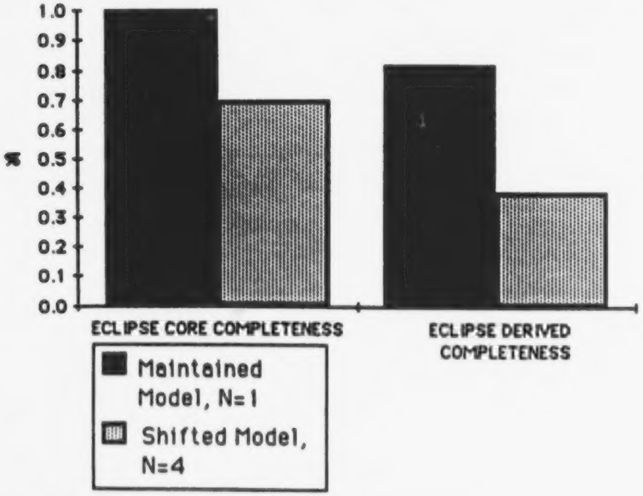


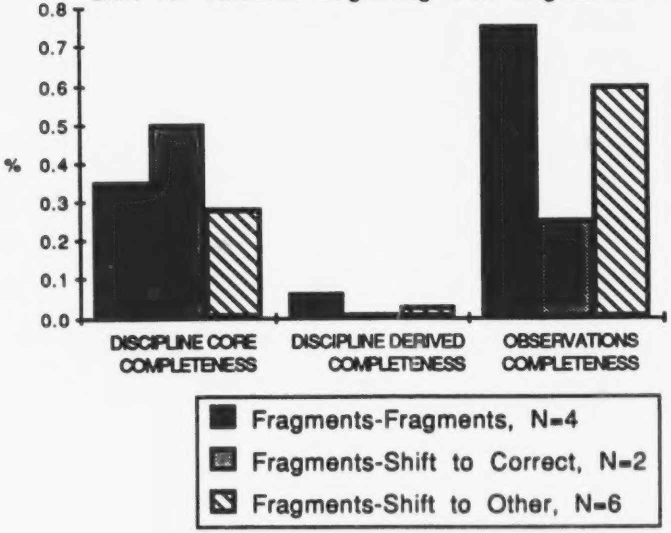
Figure 6b. Pretest completeness as a function of model retention or model switch for students starting with eclipse models.

Completeness as a function of model retention vs. model shift



As can be seen in figure 6c, the same relationship does not seem to apply to people beginning with fragments. For these people, the tendency to switch to some other models as opposed to maintaining fragments, was indeed related to incompleteness of core, derived, and observational knowledge. Those that started with more complete cores, however, were more likely to switch to the correct model. This makes sense, since those who began with more complete cores had more correct propositions that they could use to interpret the observations and extend their understanding.

Figure 6c.
Completeness as a function of model retention vs. model shift for students beginning with fragments.

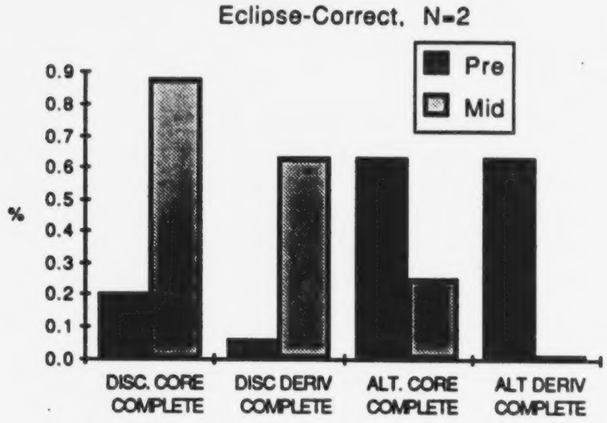


Accommodation and Assimilation

The data was analyzed to see if clear-cut cases of accommodation and assimilation could be identified. Three pre to midtest model shifts are described in these terms below.

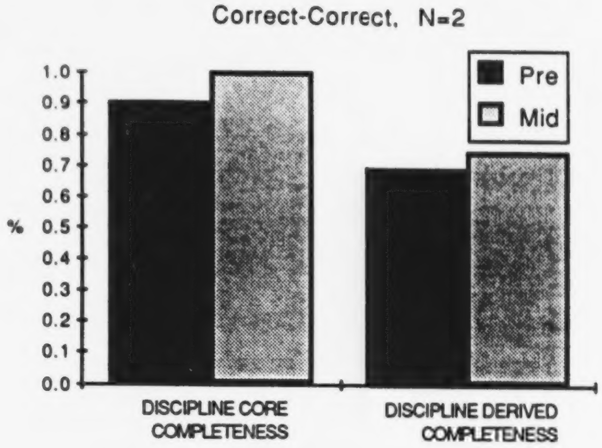
1. The two students who started with eclipse models and then by the midtest switched to the correct model displayed dramatic decreases in the completeness of both their alternative model core and their alternative model derived concepts. These decreases were compensated for by equally dramatic increases in the discipline core and derived concepts. These students are believed to represent cases of accommodation. (See figure 7.)

Figure 7. Pre to midtest changes in discipline core, discipline derived, alternative core, and alternative derived completeness for students who changed from the eclipse to the correct model.



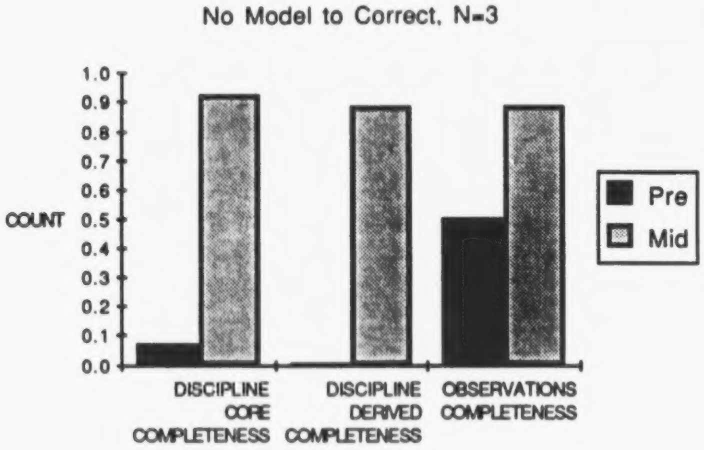
2.Students beginning and ending (as of the midtest) with the correct model were considered candidates for assimilation. These students did not, however, change substantially with respect to the completeness of their discipline-defined concepts. (See figure 8.) This may be explained by the fact that these students had largely complete (and correct) core and derived concepts to begin with, leaving little room for improvement.

Figure 8. Pre to midtest changes in discipline core and discipline derived completeness for students who maintained the correct model.



3. Also candidates for assimilation were students who began with no model and ended with the correct model. Dramatic increases in the completeness of their discipline-defined concepts and in their domain of observations can be seen in figure 9.

Figure 9. Pre to midtest changes in discipline core, discipline derived, and observation completeness for students who switched from no model to the correct model.



CONCLUSION

1. Most students in this college level introductory astronomy course began instruction with either no knowledge or very fragmentary knowledge of the phases of the moon. Teaching for accommodation, which assumes pre-existing "alternative frameworks," may not be appropriate in these circumstances.

2. Those few students who started with the correct (discipline) model had knowledge that was largely complete.

3. Even students with eclipse models or fragmentary knowledge had some correct knowledge upon which future learning can be based. The most common correct proposition was the notion that the cause of the lunar phases has something to do with the fact that the moon orbits the Earth.

4. There is a correlation between having a model for the lunar phases and being familiar with the observations.

5. After exposure to the observations, most students either adopted the incorrect "eclipse" model of the lunar phases, or acquired fragments of the correct model. Some students acquired other misconceptions, including the notion that the phases are caused by the moon going to the other side of the sun, and the notion that there are two moons, one light and one dark, that create the phases by occulting each other. This result suggests that in order to prevent misconceptions, we give advanced organizers before having students make their observations.

6. For students holding definite models, the more complete their knowledge, the less likely they were to shift to other models as a result of instruction. For students with fragmentary knowledge, those with more complete knowledge were more likely to shift to the correct model, since they knew more of the correct model to begin with. Those with less complete knowledge were likely to either remain classified as having "fragments" or to shift to other incorrect models.

7. Accommodation was seen in students who started with eclipse models and switched to the correct model. Assimilation occured in students who started with no model and acquired correct propositions. Students who

started with the correct model assimilated very little, since their models were fairly complete in the first place.

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AN APPROACH FOR HELPING STUDENTS AND TEACHERS DIAGNOSE MISCONCEPTIONS IN SPECIFIC SCIENCE CONTENT AREAS

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INTRODUCTION

In the past decade, there has been a growing world wide interest in the conceptions held by learners either prior to or following instruction in science. Much of the research has highlighted the misconceptions or alternative frameworks held by students and more recently concerns have addressed methods to improve the teaching of science concepts. Research reporting misconceptions and alternative frameworks in science has been documented by Pfundt and Duit (1986). Teaching strategies to address aspects of conceptual change have been reported in a number of countries though to date no synthesis of such teaching methods has been documented.

The work reported here is one attempt to help teachers use the findings of research to better improve their teaching. Specifically the work involves the development of multiple choice tests based on students' misconceptions. It is well documented that research findings in science education take considerable time to be applied in the classroom and the development of tests incorporating research findings, which can be readily utilized by classroom science teachers for their own purposes, would appear to be one way of improving the rate of this application. The alternative of teachers interviewing their own students to identify misconceptions is fraught with problems since not only is interviewing time consuming, it also requires substantial training (Fensham, Garrard and West, 1981).

One way for a classroom teacher to more easily identify misconceptions held by a group of students is to administer a pencil and paper multiple choice instrument which has items specifically designed to identify misconceptions and misunderstandings in a limited and clearly defined content area. Such an instrument could be used as a diagnostic tool and help a teacher to address existing misconceptions based on earlier teaching and learning prior to commencing the topic or which have occured following teaching of the topic. It is, however, well documented that the task of changing misconceptions will not be easy since misconceptions have often been incorporated securely into cognitive structure (Driver and Easley, 1978; West and Pines, 1985). Nevertheless, a teacher needs a starting place for addressing known misconceptions and a multiple choice diagnostic instrument would appear to provide a relatively straight forward method. This paper describes a methodology and its subsequent use for developing diagnostic instruments to examine and identify students' misconceptions in limited content areas of science. To date, this methodology has been used to develop three diagnostic tests; one on covalent bonding, a grade 11 and 12 chemistry topic (Peterson, Treagust and Garnett, 1986); a second on photosynthesis and respiration, a biology topic taught throughout grades 8-12 (Haslam and Treagust, 1987); and a third on solar system astronomy, a topic taught in grade 10 (Treagust and Smith, 1986).

The development of diagnostic pencil and paper instruments has been used in earlier research reported by Tamir (1971), Linke and Venz (1978, 1979), Helm (1980), Trembath (1984) and Halloun and Hestenes (1985). In Tamir's (1971) alternative approach to construction of multiple choice test items the distractors for the multiple choice items were based on students' answers to essay questions and other open-ended questions and addressed underlying conceptual knowledge related to a limited content area. Few researchers appear to have followed Tamir's approach. However, it is pertinent that Simpson and Arnold (1982, p.181) recommend that information "relating to peculiar and erroneous information held to be true by pupils" should be included in tests which depart from the usual norm-referenced paradigm. Such a recommendation has been heeded in the research work reported in this paper.

CONSTRUCTION OF DIAGNOSTIC TESTS

The methodology for diagnosing students' misconceptions in specific content areas is derived from the current literature dealing with cognitive structure and conceptual change, and comprises ten stages involving three broad areas. The stages of the methodology are briefly outlined below; further details are described by Treagust (1987).

1) The identification of propositional knowledge and the development of a concept map to define a specific content area in science.
   - Propositional knowledge statements pertinent to the topic under investigation are identified (see for example, Hackling and Treagust, 1984).
   - A map of concepts related to the topic under investigation is developed (see for example, Novak, 1980).
   - The propositional knowledge statements are related directly to the concept map in order to confirm the reliability of the underlying concepts and propositional statements.
   - The propositional knowledge statements and concept map are content validated by subject matter experts and educators.

2) Student misconceptions are identified by examining the relevant literature, by student interviews and by student responses to open ended paper and pencil questions.
   - The literature is thoroughly examined for related research on misconceptions in specific science content areas.
   - Unstructured interviews are conducted with a number of students who have recently completed a given topic, in order to identify any misunderstandings and misconceptions.

3) The development of multiple choice two-tier items, of which the first tier requires a content response and the second tier requires

1006

1007

a reason for the response.

- Multiple choice items are written based on one or a limited number of propositional statements; students are asked to provide the reason for choosing the particular option of the multiple choice item.
- A second tier of questions is developed for each item based on students' reasons for their choice as well as on information gathered from the interviews. The choice may be the correct answer, a wrong answer or an identified misconception. This technique of two-tier items for instrument development has been used by Tobin and Capie (1981).
- A specification grid is constructed to ensure that the diagnostic test addresses the propositional knowledge statements underlying the topic.
- Successive refinements of the items in the two-tier multiple choice tests ensure that the tests can be used for diagnosing student misconceptions in the topic under examination.

Based on this methodology, three diagnostic instruments from chemistry, biology and physics have been developed and completed -- at least to a useable form by classroom teachers. The three instruments Covalent Bonding and Structure, What do you know about photosynthesis and respiration in plants? and Solar System Astronomy contain 13, 15 and 5 two-tier multiple choice items respectively.

INSTRUMENTS TO HELP DIAGNOSE MISCONCEPTIONS

This paper presents two items from each of the instruments to illustrate the nature of the items, how they work and how the data can be used by classroom teachers.

Chemistry - Covalent bonding and structure

The seventh item of the Covalent Bonding and Structure test (Figure 1) assesses students' understanding of intermolecular forces and is based on three propositions, namely:

- Intermolecular forces, or weak forces of attraction, exist in varying degrees between the molecules.
- Whether a substance composed of molecules exists as a solid, liquid or gas at room temperature will depend on the magnitude of the inter-molecular forces between molecules.
- Molecular substances with high melting and boiling points have strong intermolecular forces between molecules.

The data are responses from composite grade 11 and 12 chemistry students. The majority of students in both grades (87%, 97%) responded correctly that intermolecular forces account for the differences in state of hydrogen sulphide and water at room temperature. Almost all these chemistry students were aware of the relationship which exists between the strength of the intermolecular forces and the melting point/boiling point of a substance. However, only 11% and 33% respectively correctly understood why this relationship existed. A large percentage of students (63%, 40%) selected choices 1A or 1B which relate to the strength of intermolecular bonds. These students appear to be making a consistent error and the misconception is easily identified by the teacher using this item. Indeed, the major misconception being

Water (H_2O) and hydrogen sulfide (H_2S) have similar chemical formulae and have V-shaped structures. At room temperature, water is a liquid and hydrogen sulphide a gas. The difference in state between water and hydrogen sulphide is due to the presence of strong intermolecular forces between

(1) H_2O molecules (2) H_2S molecules

Reason

A. The difference in strength of the intermolecular forces is due to differences in the strength of the O-H and S-H covalent bonds.

B. The bonds in H_2S are easily broken, whereas in H_2O they are not.

C. The difference in strength of the intermolecular forces is due to the difference in polarity of the molecules.

D. The difference in strength of the intermolecular forces is due to the fact that H_2O is a polar molecule, and H_2S is a non-polar molecule.

Grade	No of Students	Choice for first tier	Reason A	Reason B	Reason C	Reason D	Total
11	159	1	13.8	49.1	10.7*	13.8	87.4
		2	4.4	4.4	2.5	1.3	12.6
12	84	1	22.9	16.9	32.5*	24.3	97.6
		2	0.0	0.0	2.4	0.0	2.4

* the correct choice and reason response

Figure 1 : Item Number 7 from the Covalent Bonding and Structure diagnostic test showing percentage of students selecting alternative responses.

addressed, which was earlier identified by interview and in the free response format, related to the common misunderstanding that "intermolecular forces are the forces within a molecule". A second misconception addressed in choice B of item 7 was that "covalent bonds are broken when a substance changes state". This misconception, selected by 49% and 17% of the students respectively, indicates these students have not understood the nature of intermolecular forces in a molecular solid and also the strength of intermolecular forces compared with the forces within a molecule. The misconception is similar to that reported by Osborne and Cosgrove (1983) where students considered that the bonds in water molecules were broken when water changed state.

The fourteenth item of the Covalent Bonding and Structure test (Figure 2) addresses students' understanding of polar covalent bonding and is based on six propositonal knowledge statements, namely:

- Unequal sharing of the bonding electron pair results in a polar covalent bond.
- Polar covalent bonds occur between atoms with different electronegativities.
- The shared electron pair in a polar covalent bond is located closer to the atom with the higher electronegativity.
- The unequal sharing results in one nuclei being slightly negatively charged, the other slightly positively charged.
- The polarity of a polar covalent bond is symbolised by a partial positive charge (δ+) and a partial negative charge (δ-).
- The partial negative symbol is assigned to the atom with the partial negative charge, which is also the atom with the greater electro-negativity value.

The molecule SCl_2 has polar covalent bonds between the sulphur and the chlorine atoms. The atom assigned the partial positive charge ($\delta+$) in these bonds would be:

(1) Sulphur

(2) Chlorine

Reason

A. Sulphur donates one electron to the chlorine atom resulting in the formation S^+ and Cl^- ions.

B. Sulphur is partially negative ($\delta-$) as it can form an S^{2-} ion, whereas chlorine can only form a Cl- ion.

C. The number of valence electrons on sulphur and chlorine determine the polarity of the bonds.

D. Chlorine has a high electronegativity and the shared electron pair tends to be located slightly closer to it than the sulphur atom.

Grade	No of Students	Choice for first tier	Reason				Total
			A	B	C	D	
11	159	1	29.7	7.0	11.4	22.8*	70.9
		2	3.2	3.8	5.7	16.4	29.1
12	84	1	12.5	5.0	5.0	57.6*	80.1
		2	1.2	5.0	1.2	12.5	19.9

* correct choice and reason response.

Figure 2 : Item Number 14 from the Covalent Bonding and Structure diagnostic test showing percentage of students selecting alternative responses.

The misconceptions relating to bond polarity indicated confusion over the position of the electron pair in a polar covalent bond, the influence of valence electrons on the polar bond, and the influence of an ion's charge on bond polarity. Only 23% and 58% of grades 11 and 12 students respectively choose the correct response that chlorine has a high electronegativity and the shared electron pair tends to be located slightly closer to it than the sulphur atom, resulting in a partial positive charge ($\delta+$) on the sulphur atom. Thirty percent of grade 11 and 13% of grade 12 students related bond polarity to the nature of the corresponding ions formed by the atoms involved in the polar covalent bonding. In this case, the polarity of the S-Cl bond was believed to be due to S forming an S^+ ion (incorrect) and chlorine a Cl^- ion. The other misconceptions relating to bond polarity indicated alternative views developed by the students with incorrect ideas linking polar covalent bonds with valence electrons or ions. Generally, students in this sample had a poor understanding of polar covalent bonds and had not comprehended the relationship between electron sharing, position of the electron pair, and the notation for bond polarity which indicated an inadequate understanding of the underlying propositions.

Biology - photosynthesis and respiration in plants

The second item of the What do you know about photosynthesis and respiration in plants? test (Figure 3) investigates students' comprehension of the gas being taken in by plants when there is no light energy. Specifically this item addresses the following four propositional statements:

- All organisms, plants and animals, respire continually.

- Oxygen is taken in during respiration.
- Photosynthesis takes place only in the presence of light energy.
- Oxygen gas is given off by the green leaves (or green stems) during the process of photosynthesis.

The first two propositional statements are addressed directly by item 2 while the second two statements are addressed implicitly.

The data in Figure 3 are from responses of students in grades 8-10 in one school and from students in grades 11 and 12 in three schools in comparative socioeconomic areas. The results indicate that this sample of students does not have a clear understanding of the process of respiration in plants. When the first part of the item only is taken into consideration (end column), the results show that there is generally an increasingly correct response choice from grades 8-12 (39%, 44%, 41%, 65%, 88%) about which gas is taken in in large amounts by green plants when there is no light energy at all. Taking both parts of the item into consideration, the correct response is much lower (9%, 11%, 7%, 28%, 65%). While there is generally less selection of alternative reasons at each successively higher grade level, it is not until grade 12 that responses indicate that this sample of students have a reasonably clear understanding of respiration in plants. These results are perhaps surprising when one realises that respiration is taught as an identified topic in grade 8 and is addressed throughout biology units in later years of secondary school. Nevertheless, the results illustrate students' misconceptions and lack of understanding that respiration in plants is an ongoing continuous process during both light and dark conditions.

Which gas is taken in by green plants in large amounts when there is no light energy at all?

1) carbon dioxide gas
2) oxygen gas

The reason for my answer is because:

a) This gas is used in photosynthesis which occurs in green plants all the time.
b) This gas is used in photosynthesis which occurs in green plants when there is no light energy at all.
c) This gas is used in respiration which only occurs in green plants when there is no light energy to photosynthesise.
d) This gas is used in respiration which takes place continuously in green plants.
e) ______________________________

Grade	No of Students	Choice for first tier	Reason					No Reason	Total
			A	B	C	D	E		
8	137	1	14.6	16.8	10.9	16.1	-	2.9	61.3
		2	7.3	10.2	11.7	8.8*	-	0.7	38.7
9	88	1	11.4	5.7	20.5	17.0	-	1.1	55.7
		2	3.4	18.2	11.4	11.4*	-	-	44.3
10	99	1	8.1	11.1	11.2	24.2	4.0	-	58.6
		2	3.0	8.1	23.2	7.1*	-	-	41.4
11	68	1	7.4	1.5	8.8	17.6	-	-	35.3
		2	1.5	1.5	33.8	27.9*	-	-	64.7
12	49	1	-	-	6.1	6.1	-	-	12.2
		2	-	-	14.3	65.3*	4.1	4.1	87.8

* the correct choice and reason response
- no responses in this category

Figure 3 : Item Number 2 from the What do you know about photosynthesis and respiration in plants? diagnostic test showing percentage of students selecting alternative responses.

The seventh item of What do you know about photosynthesis and respiration in plants? (Figure 4) investigates students' comprehension of why plants respire and specifically addresses the following three propositional statements:

- Plants need energy to live and grow.
- During respiration plants derive energy from glucose.
- The end products of respiration are energy, carbon dioxide and water. This process may be represented by the equation:

Glucose + oxygen -> Energy + Carbon Dioxide + Water.

The correct content choice that respiration is the chemical process in which energy stored in food is released using oxygen was selected by very few students in grades 8 - 10 (34%, 14%, 10%), by less than half of grade 11 students (41%) but by most grade 12 students (84%). However, the number of students who selected the correct choice and correct reason was even lower (14%, 2%, 3%, 27%, 63%). The low percentage selection of correct response on this item in grades 8 - 10 is perhaps due to the fact that respiration in terms of energy release is not adequately emphasized in grade 8, nor in grade 9 where the emphasis is on photosynthesis, nor in grade 10 where the emphaisis is on ecology.

A relatively large percentage of students (26%, 40%, 36%, 35%) selected the first-tier response that respiration is the exchange of carbon dioxide and oxygen gases through plant stomates with the majority of these students selecting the reason being that green plants take in carbon dioxide and give off oxygen when they respire. Such selection reflects that students do not have a complete understanding of respiration as an energy producing process.

Which of the following is the most accurate statement about respiration in green plants?

1) It is a chemical process by which plants manufacture food from water and carbon dioxide.
2) It is a chemical process in which energy stored in food is released using oxygen.
3) It is the exchange of carbon dioxide and oxygen gases through plant stomates.
4) It is a process that does not take place in green plants when photosynthesis is taking place.

The reason for my answer is because:

a) Green plants never respire they only photosynthesise.
b) Green plants take in carbon dioxide and give off oxygen when they respire.
c) Respiration provides the green plant with energy to live.
d) Respiration only occurs in green plants where there is no light energy.
e) ________________________________

Grade	No of Students	Choice for first tier	Reason A	B	C	D	E	No Reason	Total
8	137	1	0.7	9.5	10.9	2.3	-	0.7	24.1
		2	3.6	14.6	13.9*	1.5	-	0.7	34.3
		3	-	18.2	5.1	2.3	-	-	25.6
		4	2.2	3.6	4.4	5.8	-	-	16.0
9	88	1	2.3	9.1	9.1	4.5	-	3.4	28.4
		2	-	9.1	2.3*	2.3	-	1.1	14.8
		3	1.1	20.5	11.4	5.7	1.1	-	39.8
		4	2.3	2.3	-	12.4	-	-	17.0
10	99	1	-	21.2	12.1	1.0	-	1.0	35.3
		2	-	6.1	3.0*	1.0	-	-	10.1
		3	1.0	24.4	9.1	1.0	-	-	35.5
		4	4.0	3.0	3.0	9.1	-	-	19.1
11	68	1	-	11.8	8.8	-	-	-	20.6
		2	-	8.8	26.5*	2.9	2.9	-	41.1
		3	1.0	16.2	14.7	-	2.9	1.5	35.3
		4	-	1.5	-	1.5	-	-	3.0
12	49	1	-	-	2.0	-	-	-	2.0
		2	-	-	65.3*	6.1	4.1	8.2	83.7
		3	-	-	6.1	-	2.1	-	8.2
		4	-	2.0	-	4.1	-	-	6.1

* The correct choice and reason response
- No responses in this category

Figure 4 : Item Number seven from the What do you know about photosynthesis and respiration in plants? diagnostic instrument showing percentage of students selecting alternative responses.

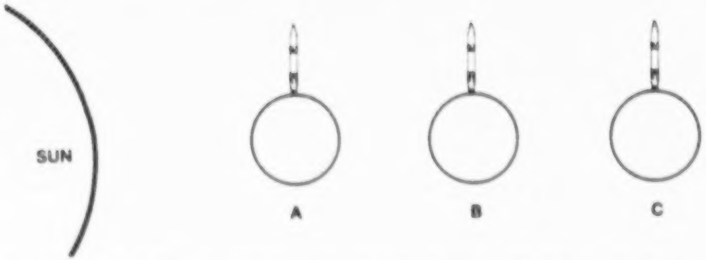
Only in grade 12 have students in this sample developed an accurate and more complete conception of respiration. Student responses to the items on this biology diagnostic test on photosynthesis and respiration in plants are consistent with research reported by Bell (1984), Roth, Smith and Anderson (1983) and Wandersee (1983).

Physics - Planetary Motion

On the Solar System Astronomy test a small number of items were written around propositions underlying the content being taught in grade 10. The first three items addressed the concept of gravitational forces of planets and the Sun and examined the following propositions:

- Gravity is the force of attraction between bodies.
- The larger the mass of a body in the Solar System, the larger is its gravitational field.
- The greater the distance from a Solar System body, the weaker the gravitational field.

The Solar System Astronomy test was administered to 113 grade 10 students in two schools a few weeks after instruction. Student responses on the first item where the solar system is fictitious (Figure 5) provided evidence that 57% believed, despite the equal sizes of the planets, that the planet which is furthest away from the Sun has the least gravitational field; hence in this item, students believed that the rocketship will be able to leave easiest from the planet furthest away from the Sun. A relatively small percentage of students (18%) correctly selected responses that since all planets are the same size, they will have the same gravity or gravitational field and the rocketships will take off as easily from all planets. As in other items, a



In this solar system, there are three planets of the same size. An identical rocketship is ready to leave each planet. Which planet will be easiest for the rocketship to "take off" from?

1. Planet A
2. Planet B
3. Planet C
4. The rocketship will take off from all planets as easily
5. It is not possible to tell.

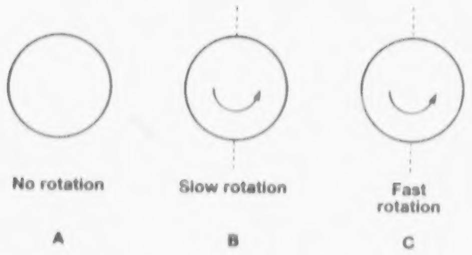
Reason:

a) Planet C, which is furthest from the Sun, has less gravitational pull from the Sun.
b) Planet A, which is closest to the Sun, has the highest surface temperature.
c) Planet B, which is neither too hot nor too cold, nor is too close to the Sun.
d) Since all planets are the same size, the rocketship will take off from all the planets as easily.
e) ______________________________

	Response and Reason	% with this choice
3A	Planet C is furthest from the Sun and has less gravitational pull from the Sun	57%
4D*	Since all planets are the same size, the rocketship will take off from all planets as easily	18%
2C	Planet B is neither too hot nor too cold, nor is too close to the Sun	11%
	All other choice combinations	14%

* The correct choice and reason response

Figure 5 : Students' responses to the first two-tier item on the diagnostic test Solar System Astronomy (n = 113)



In this solar system, there are three identical sized planets rotating at different speeds. An identical rocketship is ready to leave each planet. Which planet will be easiest for the rocketship to "take off" from?

1. Planet A
2. Planet B
3. Planet C
4. The rocketship will take off from all planets as easily
5. It is not possible to tell.

Reason:

a) Lack of rotation makes the rocketship leave the planet easier.
b) The rotation is not too fast and does not hold things down.
c) Especially if the rocketship leaves in the same direction as the rotating planet.
d) The rotation will not make any difference to the planet's gravity.
e) ______________________________

	Response and Reason	% with this choice
1A	Planet A, since lack of rotation makes the rocketship leaving the planet easier	47%
2B	Planet B, since the rotation is not too fast and does not hold things down	16%
4D*	The rocketship will take off from all planets as easily since the rotation does no make any difference to the planet's gravity	9%
	All other choice combinations	28%

* The correct choice and reason response

Figure 6 : Students' responses to item four on the diagnostic instrument Solar System Astronomy (n = 113)

small percentage of students (11%) related a planets' gravity to the proximity of the Sun and the effect of the Sun's heat.

Item 4 of the Solar System Astronomy test examined the concept of planetary rotation in relation to gravity (Figure 6) and examined the following propositions:

- When a planet or satellite turns on its own axis it is rotating
- Gravity is the force of attraction between bodies.

A large percentage of students (47%) believed that a planet which was not rotating would allow easiest take off by the rocketship. These students connected "no rotation with low gravity" and saw no conflict in this concept. Similar responses were reported by Stead and Osborne (1980) where students believed gravity was caused by the Earth spinning. Other students in this sample (16%) rationalized that a planet which is not rotating too quickly, Planet B, was most likely to allow easiest take off by the rocketship. Only a small percentage (9%) of this student sample believed that rotation of the planet did not affect its gravitational field. In interviews, several students likened the rotation of a planet to confused concepts about swinging buckets of water around the head where the water does not fall out and swinging stones around the head and feeling the tension in the string and comparing this with gravity. The actual source of these conceptions was not investigated further in this study.

IMPLICATIONS FOR IMPROVING SCIENCE TEACHING

The results of reported research on students' misconceptions are illustrative of students' thinking and perhaps the failings of the implemented curricula, but these findings are not easily used by classroom practitioners. One possible means of increasing the application of science misconceptions research into the classroom is by incorporating the findings of this research into diagnostic tests which can be used by teachers as an integral part of their own teaching. The use of reliable and valid pencil and paper, easy-to-score diagnostic tests at the beginning or upon completion of a specified science topic can enable a science teacher to obtain clearer ideas about the nature of the students' knowledge and their misconceptions in a topic. Further, we have found that student discussion of their responses to these diagnostic test items has greatly enhanced their interest in the content being taught and learned. In the biology and physics diagnostic tests reported here students were instructed to complete their own reason in the second tier of each item if the stated reason responses did not match their own explanation. The opportunity for students to write down their own reasoning is one means for the classroom teacher to identify further misconceptions or misunderstandings held by students prior to or following instruction. Once misconceptions are more easily identified, a science teacher will be more inclined to remedy the problem by developing and/or utilising alternative teaching approaches which address students' misconceptions. However, even with a different teaching approach, research has shown that misconceptions are persistent and may be retained.

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Children's Biology:
A Content Analysis of
Conceptual Development in the Life Sciences

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Introduction

Since Piaget's early work (1929), a significant body of evidence has amassed which indicates that children bring to their earliest school experiences a wide variety of firmly held alternative interpretations of natural phenomena. These naive theories (Resnick, 1983), preconceptions (Ausubel, Novak, and Hanesian, 1978), misconceptions (Arnaudin, 1983), private concepts (Sutton, 1980), underlying sources of error (Fisher and Lipson, 1986), limited or inappropriate propositional hierarchies (Novak, 1983), alternative conceptions (Waterman, 1983), student frameworks (Erickson, 1983), and alternative frameworks (Driver, 1981) help pupils make sense of their physical and biological surroundings.

Gilbert et al. (1982) and Osborne et al. (1983) have called these notions "children's science" and assert that they possess several recognizable characteristics. Among these characteristics are the use of everyday language to interpret science concepts (sometimes attaching naive meanings to technical terms), egocentric, anthropocentric, and animistic viewpoints, the tendency to dismiss nonobservables as non-existent, and the endowment of objects with a certain amount of physical quantity.

It is now clear that many of these notions have the potential to interfere with learning (Fisher & Lipson, 1986) and are highly resistant to extinction even by well-planned instruction, often "ossifying into layman's science" in later years (Strike and Posner, 1982). Many times children learn scientifically acceptable viewpoints by rote and apply them in school situations but revert to prior theories when confronted with a novel problem.

In an article suggesting appropriate research for biology education, Stewart (1980) observed, "It is time we began treating the content of science as an important research focus." Since the time of his clarion call, the number of studies which focus on students' conceptual development in the life sciences has increased dramatically. Indeed, misconception research in general is now "well represented in the literature" (Gabel et al., 1986).

Yet many biology educators may not be aware of the extant conceptual development research. For example, Griffiths and Grant (1985) assert that "Very few misconceptions studies have related to biological concepts . . ." and Marek (1986) contends that ". . . a paucity of research exists regarding high school students' understandings and misunderstandings of biology concepts." Although such perceptions are invalid, they are understandable since misconception studies in the life sciences are published in various journals throughout the world and are both hard to find and difficult to retrieve.

A 1978 review by Driver and Easley provided a helpful overview of more than 50 years of research on conceptual development among adolescent science students. That review concentrated on conceptual development in the *physical sciences*, with special attention to British and European work. Although its analytical approach differs, this article seeks to complement the work of Driver and Easley by summarizing research efforts on conceptual development in the *biological sciences*. In doing so, we have analyzed 103 studies originating in North America, Europe, Asia, the British Isles, Asia, Africa, and Australia.

Consequently, the purpose of this investigation was to analyze published research on students' conceptual development in the life sciences with the intent of providing information on trends and content of those studies. A content analysis was designed to yield frequency indices of research activity and practice as measures of importance, attention, and emphasis (Krippendorff, 1980). We hope this analysis will serve both as a useful source of preliminary information and as an impetus for discussion concerning the implications of the findings.

Method

Content Analysis

The term *content analysis* was first used in 1945 and can be defined as "analysis of the manifest and latent content of a body of communicated material . . . through a classification, tabulation, and evaluation of its key symbols and themes in order to ascertain its meaning and probable effect" (Merriam-Webster, 1983).

Content analysis is considered one of the most important methods in communications research. Since published research studies are documents vital to the understanding of what we know about pupils' conceptual development in the life sciences, we assume that the quantitative description of communication content will be meaningful (Berelson, 1952).

Locating Studies

In attempting to locate as many relevant studies as possible we employed both computer-based information searches and conventional hand searches. Two library data bases were computer-searched through Lockheed's DIALOG Online Information Service. These included the ERIC data base composed of the two files *Research in Education* and *Current Index to Journals in Education*, and *Comprehensive Dissertation Abstracts*.

The computer searches were supplemented by hand searches of the following journals: *American Biology Teacher*, *Australian Science Teachers Journal*, *Child Development*, *Developmental Psychology*, *European Journal of Science Education*, *Journal of Biological Education*, *Journal of Genetic Psychology*, *Journal of Research in Science Teaching*, and *Science Education*. All issues from 1963 or date of original publication (whichever came later) through mid-1986 were searched and relevant bibliographic citations were followed up. It is assumed that the search strategy employed uncovered many of the target studies published in the English language.

Procedure

The studies located were subjected to a coding process that used the following "recording units" as the separately analyzable parts of the sampling unit: concepts investigated, publication source, year of publication, research method employed, length of the published report, and the principal findings of the study (Holsti, 1969; Egginton, 1983).

When classified by concepts, five distinct groups of studies were identified by the researchers. These include pupil's concepts of life (living vs. nonliving) and death; plants and animals; the human body; biological continuity (reproduction, genetics, evolution); and other biological phenomena. This system partitioned the 103 studies into five categories with approximately twenty studies in each category.

Results

Concepts Investigated

The data presented in Table 1 show that the largest number of studies of students' conceptual development in the life sciences were done in the area of *biological continuity* (reproduction, genetics, evolution). Although another category, *other biological phenomena*, contained three more studies, it also included a great diversity of topics from cells to food webs. Thus, it actually represents those topics generating only slight research interest.

Table 1

Categorical Distribution Pattern of Studies of Students' Conceptual Development in the Life Sciences

Category	No. of Studies
Life and Death	17
Plants and Animals	20
Human Body	16
Biological Continuity	23
Other Biological Phenomena	27

Note. Total number of studies = 103.

Publication Sources

Analysis of the publication sources of the studies we located revealed the following: studies of students' conceptual development in the life sciences are most likely to be found in the *Journal of Biological Education*, the *Journal of Research in Science Teaching*, or the *Journal of General Psychology*. Table 2 summarizes the source of publication data for the 103 studies we found. It should be noted that although *The American Biology Teacher* is credited with just three studies, it does have a department of "Research Reviews" that looks at educational research in which biology is the content. While the column is not a regular feature of that journal, it is worthy of recognition here.

Table 2

Sources Containing Studies on Students' Conceptual Development in the Life Sciences

Publication	No. of Studies
Journal of Biological Education	15
Journal of Genetic Psychology	15
Journal of Research in Science Teaching	14
Science Education	6
Proceedings of International Seminar	6
European Journal of Science Education	5
Child Development	5
Ph.D. dissertations	5
Australian Science Teachers Journal	4
American Biology Teacher	3
Developmental Psychology	3
Other sources (less than 3 studies each)	22

Note. Total number of studies located = 103.

Year of Publication

Table 3 provides information on the number of published studies of students' conceptual development in the life sciences grouped by decade. Note the decade by decade increase in the number of studies. The data for the 1970s show a dramatic increase in the number of articles appearing in the sources we examined. In the 1980s, research interest continues to increase as evidenced by the number of publications we recorded up to mid-1986.

Table 3

Published Studies of Students' Conceptual Development in the Life Sciences by Decade

Decade	No. of Studies
1930s	1
1940s	3
1950s	4
1960s	12
1970s	36
1980s	47

Note. Total number of studies = 103.

Research Methods Employed

A wide variety of research methods was used to gather the data for the studies of students' conceptual development in the life sciences that we examined. Table 4 shows the range of methods and also demonstrates that the interview method was the one most often used by researchers in this field.

Length of Published Report

Space measurement, defined here as the number of pages assigned to the articles by the editor of the publication, is also an indirect way of measuring the journal readership's interest in an area. Table 5 shows that the number of pages devoted to studies of students' conceptual development in the life sciences increased by 184 pages (70%) from the 1970s to the 1980s. (It should also be noted that the seemingly high number of pages for the 1940s was unduly influenced by two long research articles written by the same person.)

Table 4

Research Methods Used in Studies of Students' Conceptual Development in the Life Sciences

Method	No. of Studies
Interviews	47
Multiple-Choice Tests	21
Sorting Tasks	20
Student-Made Drawings	9
Questionnaires	8
Open-Ended Tests	7
Classification Tasks	6
Association Tasks	6
Essay Writing	6
Identification Tasks	5
Concept Mapping	4
Problem Solving Tests	4
Piagetian Tasks	4
Other Methods (used less than four times each)	20

Note. Since some of the studies used more than one method, the total number of studies sum to 167, not 103.

Table 5

Space Measurements of Studies of

Students' Conceptual Development in the Life Sciences

by Decade

Decade	Journal Pages Devoted to these Studies
1930s	6
1940s	106
1950s	38
1960s	205
1970s	264
1980s	448

Note. For the purposes of this table, only journal article space measurements were included here. Space measurement was used to estimate coverage based on findings of Windhauser & Stempel (1979).

Interpreting the Results

Our purpose was to analyze published research on students' conceptual development in the life sciences in order to provide information on trends and content of those studies. Our intent was to conduct a content analysis (not a critical review of the literature) which could serve as a useful source of preliminary information and as a springboard for discussions concerning the theoretical implications of the findings.

A profile of the most common study would read as follows: 1) topic--biological continuity; 2) research method--interview; 3) median number of subjects in the study--100; 4) decade of publication--1980s; and 5) journal of publication--Journal of Biological Education or the Journal of Genetic Psychology. Yet as our study shows, there is considerable variation from study to study.

Although we made great efforts to locate relevant studies of students' conceptual development in the life sciences, we realize that we may have unintentionally overlooked some important contributions. It is also possible that in summarizing the major findings of each research study we may have omitted or misrepresented the findings of a particular study. We have taken great precautions to avoid such errors but we admit the potential exists. In a way, summarizing the research literature in this area is as difficult as hitting a moving target. Research continues and characteristics shift as new studies are published.

The findings presented in this analysis were gathered from more than 23,500 subjects across six decades. Theoreticians such as Champagne et al. (1980), Driver and Bell (1986), Erickson (1979, 1981), Fisher and Lipson (1986), Hewson (1981), Novak (1982, 1983), Nussbaum and Novick (1981a, 1981b), Posner et al. (1982), and Shayer and Wylam (1981) are still debating the nature of children's naive theories in science and appropriate ways to facilitate conceptual change. Although the jury is still out, new and improved science instruction is bound to come.

The future of any research effort depends on the productivity and the longevity of a research community. It seems clear from this content analysis that a scholarly research community interested in conceptual development is present, active, and growing in biology education.

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